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(54) **MICRO-RELAY AND METHOD FOR MANUFACTURING THE SAME**

MIKRO RELAIS UND VERFAHREN ZU SEINER HERSTELLUNG

MICRO-RELAIS ET SON PROCEDE DE FABRICATION

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Description

TECHNICAL FIELD

[0001] The present invention relates to electronic components such as micro-relays, and in particular micro-relays, matrix relays and micro-relay chips having contacts which are opened and closed by curving a movable piece constructed of a monocrystal thin plate-shaped substrate.

BACKGROUND ART

[0002] Conventionally, as a relay, there has been, for example, an electromagnetic relay utilizing an electromagnet. However, the relay, which necessitates mechanical components, is hard to be reduced in size. Furthermore, the movable components of the mechanical components, which have great inertial forces, tend to disadvantageously cause fatigue failure and lack in durability.

[0003] There is otherwise existing a semiconductor switching device as a sort of small-sized relay, however, the device disadvantageously has a great resistance in turning on its contact, degraded frequency characteristics and a low insulating property between its input and output and between its terminals of an identical polarity.

[0004] In view of the aforementioned problems, the present invention has a first object to provide a subminiature micro-relay that has a small resistance in turning on its contact as well as the desired vibration resistance, frequency characteristics and insulating property.

[0005] A micro-relay according to the preamble of claim 1 is known from JP 6 -33 82 44 A and US 5 479 042.

DISCLOSURE OF THE INVENTION

[0006] The invention is as defined in claim 1.

[0007] According to the invention, the movable contact is pivotally supported, and this eliminates the one-side hitting of the movable contact against the fixed contact and improves the contact reliability.

[0008] A second feature is a micro-relay in which a device wafer is connected and integrated with an opening edge portion of a box-shaped base comprised of a handle wafer via an insulating film, and the movable piece is formed by cutting a pair of slits through the device wafer.

[0009] According to the second feature, the movable piece is formed on the device wafer connected and integrated with the box-shaped base of the handle wafer. This arrangement allows the manufacturing processes to be wholly achieved by the semiconductor manufacturing techniques.

[0010] The handle wafer and the device wafer are connected and integrated with each other via the insulating film, and therefore, the wafers can be connected and integrated with each other at a temperature lower than in directly connecting and integrating silicon objects. For

this reason, a material having a low melting point can be used for the fixed contact and the movable contact, allowing the degree of freedom of design to be expanded.

[0011] A third feature is a micro-relay in which the device wafer is formed with a connecting use opening portion in a position opposite to a connecting pad of the fixed contact provided on a bottom surface of the handle wafer.

[0012] According to the third feature, connection to the outside can be achieved by utilizing wire bonding via the connecting use opening portion provided at the device wafer. This allows the wiring structure of the micro-relay itself to be simplified for easy manufacturing.

[0013] A fourth feature is a micro-relay in which the inside surface of the connecting use opening portion is covered with an insulating film.

[0014] According to the fourth feature, the inside surface of the connecting use opening portion is covered with an insulating film. Therefore, even when wire bonding is performed, the wire is not brought in contact with the silicon layer, and it is not interfered by the driving use power source.

[0015] A fifth feature is a micro-relay in which a cooling fin is formed on the upper surface of the device wafer.

[0016] According to the fifth feature, heat generated from the movable piece speedily dissipates to the outside via the cooling fin formed on the upper surface of the device wafer. This improves the operating characteristics in the restoration stage.

[0017] Even when micro-relays are integrated with each other, the cooling fin efficiently radiates heat, so that malfunction due to overheat can be prevented.

[0018] A sixth feature is a micro-relay in which the movable piece is previously curved and urged so as to bring a movable contact provided on its one surface in contact with a fixed contact that faces the movable contact.

[0019] According to the sixth feature, the thin plate-shaped substrate is previously curved to bring the movable contact in contact with the fixed contact, and therefore, a self-retaining type micro-relay can be obtained, allowing the power consumption to be remarkably reduced.

[0020] A seventh feature is a micro-relay in which a pair of pivot axes that are coaxially provided projecting roughly from a center portion between both side edge portions of the movable contact are supported on the base, one side half of the thin plate-shaped substrate is previously curved and urged upward, the remaining side half is previously curved and urged downward and the one side halves are simultaneously reversely buckled via the driving means, thereby alternately making and breaking two electric circuits.

[0021] According to the seventh feature, the one side half of the thin plate-shaped substrate can be simultaneously reversely buckled for opening and closing the contacts, and this allows the simultaneous making and breaking of a plurality of electric circuits.

[0022] An eighth feature is a micro-relay in which the driving means is a piezoelectric element laminated on

one surface of the thin plate-shaped substrate.

[0023] According to the eighth feature, the movable piece is curved by the piezoelectric element, and this allows the obtainment of a micro-relay that can save the power consumption attributed to heat generation and has good energy efficiency.

[0024] A ninth feature is a micro-relay in which the driving means is a heater layer formed on one surface of the thin plate-shaped substrate.

[0025] According to the ninth feature, the movable piece is curved by only the heater layer, and this allows the obtainment of a micro-relay that necessitates a reduced number of manufacturing processes and has a high productivity.

[0026] A tenth feature is a micro-relay in which the driving means is comprised of a heater layer formed on one surface of the thin plate-shaped substrate and a driving layer formed by laminating a metal material on the heater layer via an insulating film.

[0027] According to the tenth feature, the driving layer is formed by laminating the metal material having a high coefficient of thermal expansion, and this allows the obtainment of a micro-relay that has an excellent response characteristic and a great contact pressure.

[0028] An eleventh feature is a micro-relay in which the heater layer of the driving means is comprised of a metal material such as platinum or titanium or a polysilicon laminated on the one surface of the thin plate-shaped substrate via an insulating film.

[0029] According to the eleventh feature, the heater layer is formed by laminating the metal material or polysilicon on the one surface of the thin plate-shaped substrate, and this allows the obtainment of a heater layer that has a high dimensional accuracy. Therefore, a micro-relay having uniform operating characteristics can be obtained.

[0030] A twelfth feature is a micro-relay in which the driving means is a heater section comprised of a diffused resistor formed inside the thin plate-shaped substrate.

[0031] According to the twelfth feature, the driving means is the diffused resistor formed inside the thin plate-shaped substrate made of the monocrystal. Therefore, the generated heat can be effectively utilized, allowing the obtainment of a micro-relay having a small heat loss.

[0032] A thirteenth feature is a micro-relay in which an insulating film is formed on at least one of the front surface or the rear surface of the movable piece, the surface being formed with the movable contact.

[0033] According to the thirteenth feature, the insulating film ensures the insulating property and prevents the leak of heat generated from the driving means.

[0034] A fourteenth feature is a micro-relay in which silicon compound films that are made of a silicon oxide film, a silicon nitride film or the like and have different thickness values are formed on the front and rear surfaces of the movable piece.

[0035] According to the fourteenth feature, the silicon

compound film is formed on the front and rear surfaces of the movable piece, and this prevents the leak of heat generated from the movable piece, allowing the obtainment of a micro-relay having a good thermal efficiency.

[0036] A fifteenth feature is a micro-relay in which a silicon compound film comprised of a silicon oxide film, a silicon nitride film or the like for giving at least one side of the movable piece a compressive stress in proximity to a critical value at which driving starts.

[0037] According to the fifteenth feature, the compressive stress in proximity to the critical value at which driving starts can be obtained from the silicon compound film, and this allows the obtainment of a micro-relay having a good response characteristic.

[0038] A sixteenth feature is a micro-relay in which at least one adiabatic slit is formed near both end portions of the movable piece.

[0039] According to the sixteenth feature, the adiabatic slit is formed near both the end portions of the movable piece. Therefore, the heat conducting area becomes small to allow the prevention of heat conduction from both the end portions of the movable piece. As a result, the energy can be effectively utilized, thereby allowing the response characteristic to be improved.

[0040] A seventeenth feature is a micro-relay in which the adiabatic slit is filled with a polymer material having low heat conductivity.

[0041] According to the seventeenth feature, the adiabatic slit is filled with the polymer material having low heat conductivity. With this arrangement, the energy can be more effectively utilized, thereby allowing the response characteristic to be improved.

[0042] An eighteenth feature is a micro-relay in which the movable piece is extended across the base via an adiabatic silicon compound portion formed in both end portions of the movable piece.

[0043] According to the eighteenth feature, heat is hard to be conducted to the base from both the end portions of the movable piece, so that the utilization of energy and the improvement of the operating characteristics can be achieved.

[0044] A nineteenth feature is a micro-relay in which a root portion of the movable piece is provided with a radius for alleviating stress concentration.

[0045] According to the nineteenth feature, by providing the root portion of the movable piece with the radius, the fatigue failure due to stress concentration is hard to occur, so that the operating life is prolonged.

BRIEF DESCRIPTION OF THE DRAWINGS

[0046]

Fig. 1 is a schematic sectional view showing a micro-relay according to a first embodiment (not claimed);

Fig. 2A is a detailed plan view of the micro-relay shown in Fig. 1;

Fig. 2B is a sectional view of the micro-relay bisected;
 Fig. 2C is a sectional view taken along the line 2C-2C in Fig. 2A, showing an integrated state;
 Fig. 3A through Fig. 3E are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 4A through Fig. 4D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 5A through Fig. 5D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 6A through Fig. 6D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 7A through Fig. 7D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 8A through Fig. 8D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 9A through Fig. 9C are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 10A through Fig. 10C are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 11A through Fig. 11E are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 1;
 Fig. 12A is a plan view showing a micro-relay according to a second embodiment (not claimed);
 Fig. 12B is a sectional view of the micro-relay bisected;
 Fig. 12C is a sectional view taken along the line 12C-12C in Fig. 12A, showing an integrated state;
 Fig. 13A through Fig. 13E are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 12A through Fig. 12C;
 Fig. 14A through Fig. 14D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 12A through Fig. 12C;
 Fig. 15A through Fig. 15D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 12A through Fig. 12C;
 Fig. 16A through Fig. 16D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 12A through Fig. 12C;
 Fig. 17A through Fig. 17D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 12A through Fig. 12C;
 Fig. 18A through Fig. 18D are sectional views showing the manufacturing processes of the movable contact block shown in Fig. 12A through Fig. 12C;
 Fig. 19 is a sectional view showing the manufacturing process of the movable contact block shown in Fig. 12A through Fig. 12C;
 Fig. 20A is a plan view showing a micro-relay ac-

cording to a third embodiment (not claimed);
 Fig. 20B is a sectional view of the micro-relay bisected;
 Fig. 20C is a sectional view taken along the line 20C-20C in Fig. 20A, showing an integrated state;
 Fig. 21 is a perspective view showing a micro-relay according to a fourth embodiment (not claimed);
 Fig. 22 is a plan view of the micro-relay shown in Fig. 21;
 Fig. 23A through Fig. 23J are sectional views showing the manufacturing processes of the handle wafer of the micro-relay shown in Fig. 21;
 Fig. 24A through Fig. 24H are sectional views showing the manufacturing processes of the device wafer of the micro-relay shown in Fig. 21;
 Fig. 25A through Fig. 25F are sectional views showing the manufacturing processes after the connection of the wafer shown in Fig. 23A through Fig. 24J;
 Fig. 26A through Fig. 26F are sectional views showing the manufacturing processes after the connection of the wafer shown in Fig. 23A through Fig. 24J;
 Fig. 27 is a plan view showing a micro-relay according to a fifth embodiment (not claimed);
 Fig. 28 is a perspective view showing a micro-relay according to a sixth embodiment (not claimed);
 Fig. 29 is an enlarged perspective view of the fin shown in Fig. 28;
 Fig. 30 is a plan view showing a micro-relay according to a seventh embodiment of the present invention;
 Fig. 31 is a plan view showing a micro-relay according to an eighth embodiment which is an embodiment of the present invention;
 Fig. 32 is a plan view showing a micro-relay according to a ninth embodiment (not claimed);
 Fig. 33 is a perspective view showing a micro-relay according to a tenth embodiment (not claimed);
 Fig. 34 is a sectional view showing a micro-relay according to an eleventh embodiment (not claimed);
 Fig. 35 is a sectional view showing a micro-relay according to a twelfth embodiment (not claimed);
 Fig. 36 is a sectional view showing a micro-relay according to a thirteenth embodiment (not claimed);
 Fig. 37A is a graph showing the theoretical operating characteristics of a micro-relay that utilizes a piezoelectric element, and in particular, a relation between an application voltage and a contact load;
 Fig. 37B is a graph showing a relation between the application voltage and a displacement;
 Fig. 38A is a graph showing the theoretical operating characteristics of a micro-relay that concurrently uses a heater layer for a driving layer, and in particular, a relation between a temperature rise and the contact load;
 Fig. 38B is a graph showing a relation between the temperature rise and the displacement;
 Fig. 39A is a plan view showing the micro-relay of a fourteenth embodiment that is a matrix relay;
 Fig. 39B is a sectional view taken along the line

39B-39B in Fig. 39A;

Fig. 40 is a sectional view taken along the line 40-40 in Fig. 39A;

Fig. 41A is a matrix circuit diagram showing the circuit of the matrix relay of Fig. 39A and Fig. 39B;

Fig. 41B is a circuit diagram redrawn for providing a better view of Fig. 41A;

Fig. 42A is a plan view showing a matrix relay according to a fifteenth embodiment (not claimed);

Fig. 42B is a sectional view taken along the line 42B-42B in Fig. 42A;

Fig. 43 is a sectional view taken along the line 43-43 in Fig. 42A;

Fig. 44 is a perspective view of a sixteenth embodiment showing a number of movable pieces arranged parallel for constituting a matrix relay; and

Fig. 45 is a circuit diagram of a matrix relay according to a seventeenth embodiment, constructed of a number of relay elements.

BEST MODE FOR CARRYING OUT THE INVENTION

[0047] Embodiments of the present invention will be described next with reference to the accompanying drawings of Fig. 1 through Fig. 45.

[0048] As shown in Fig. 1, a micro-relay according to the first embodiment is formed of a movable contact block 10 on the upper surface of which both ends of a movable piece 20 are fixed and supported and a fixed contact block 30 that is anodically bonded to this movable contact block 10. Then, a movable contact 25 provided on the upper surface of the movable piece 20 faces a pair of fixed contacts 38 and 39 formed on the ceiling surface of the fixed contact block 30 while being able to come in and out of contact with the fixed contacts.

[0049] That is, as shown in Fig. 2A through Fig. 2C, a base 11 constituting the movable contact block 10 is made of a wafer of silicon, glass or the like.

[0050] The movable piece 20 is provided by integrating a driving means for curving the movable piece in the direction of thickness with the upper surface of a thin plate-shaped substrate 21 made of a monocrystal of silicon or the like via an insulating film. Then, this driving means is constructed by laminating a driving use lower electrode and upper electrodes 22 and 23 on the front and rear surfaces of a piezoelectric element 24.

[0051] The fixed contact block 30 is constructed of a wafer 31 of glass, silicon or the like and formed with input and output use through holes 32 and 35 and driving use through holes 33 and 34.

[0052] The input and output use through holes 32 and 35 are electrically connected to the fixed contacts 38 and 39, respectively, via printed wiring lines 36 and 37 formed on the lower surface of the wafer 31. Further, the input and output use through holes 32 and 35 are provided with connecting pads 32a (not shown) and 35a, which are constructed of a conductive material and located at their lower end portions, in order to increase the reliability

of connection to the printed wiring lines 36 and 37.

[0053] On the other hand, the driving use through holes 33 and 34 are provided with connecting pads 33a and 34a, which are constructed of a conductive material and located at their lower end portions, so that the through holes can be connected to the driving use lower and upper electrodes 22 and 23.

[0054] According to the present embodiment, the connecting points are aligned in an identical plane via the through holes 32 and 35, and this provides the advantage that the connection is made easy.

[0055] A manufacturing method of the above-mentioned micro-relay will be described next.

[0056] As shown in Fig. 2A through Fig. 2C, the present embodiment adopts the assembling method of manufacturing the movable contact block 10 and the fixed contact block 30 through different processes and thereafter integrating them with each other by anodic bonding.

[0057] It is to be noted that Fig. 3A through Fig. 10C show local sectional views showing only the important parts for the sake of convenience of explanation.

[0058] First, for the movable contact block 10 as shown in Fig. 3A through Fig. 3E, a thermal oxidation film (thermal SiO_2) that becomes a mask material for TMAH (tetramethyl ammonium hydroxide) etching is formed on the front and rear surfaces of a first silicon wafer 11a that serves as the base 11 and has a thickness of 400 μm and a crystal orientation of 100. Then, a resist is coated, and a pattern for performing the TMAH etching is formed by photolithography. Next, the thermal oxidation film is etched and thereafter the resist is removed.

[0059] Next, as shown in Fig. 4A through 4C, the silicon wafer 11 is etched by TMAH so as to form a cavity, and thereafter a silicon nitride film that becomes a mask material is laminated on the front and rear surfaces thereof. Then, the silicon nitride film and the thermal oxidation film on the front surface side are removed by dry etching and oxide film etching.

[0060] On the other hand, a high-concentration B (boron) and Ge (germanium) layer is made to epitaxially grow to a thickness of 2 μm on one surface of the silicon wafer having the thickness of 400 μm and the crystal orientation of 100. Further, a normal-concentration B layer is made to epitaxially grow to a thickness of 20 μm on its surface, thereby obtaining a second silicon wafer 21a for forming the thin plate-shaped substrate 21. Then, the B layer of this second silicon wafer 21a is placed on the upper surface of the first silicon wafer 11a and integrated with the same by direct bonding (see Fig. 4D).

[0061] Then, as shown in Fig. 5A through Fig. 5D, the surface of the second silicon wafer 21a is etched by TMAH for thinning. Through this process, the etching stops in the high-concentration B and Ge layer that has epitaxially grown, and the normal-concentration B layer that has epitaxially grown is exposed, thereby forming the thin plate-shaped substrate 21. Next, LTO (low-temperature oxide film) that serves as a protecting film for the lower electrode 22, which will be described later, is

formed on the front surface of the exposed B layer. Then, by successively laminating titanium (Ti) and platinum (Pt) by sputtering, the lower electrode 22 is formed. Further, a piezoelectric film (PZT) of lead zirconate titanate or the like is formed by sputtering.

[0062] Subsequently, as shown in Fig. 6A through Fig. 6D, a resist is coated and a pattern of the piezoelectric film is formed by photolithography. Then, after etching by RIE (Reactive Ion Etching), the resist is removed, thereby forming the piezoelectric element 24. Subsequently, an insulating film is formed by SOG (Spin On Glass) coating. The reason why SOG is used is that the piezoelectric film possibly changes its characteristics when heated and intended to form an insulating film without heating. Then, a resist is coated and a pattern is formed by photolithography. Further, after exposing the piezoelectric element 24 by removing the center portion of the insulating film, a platinum (Pt) thin film that becomes an upper electrode 23 is deposited by sputtering.

[0063] Subsequently, as shown in Fig. 7A through 7D, a resist is coated on the platinum thin film, and the pattern of the upper electrode 23 is formed by photolithography. Then, the unnecessary platinum is etched away to form the upper electrode 23, and the resist is removed. Further, a resist is coated, and a pattern for etching the insulating film of SOG located between the lower electrode 22 and the upper electrode 23 is formed by photolithography.

[0064] Subsequently, as shown in Fig. 8A through 8D, the insulating film of SOG is etched by photolithography for the formation of a pattern of the insulating film between the lower electrode 22 and the upper electrode 23 and thereafter the photoresist is removed. Then, an insulating film SiO₂ for insulating between the upper electrode 23 and the movable contact 25, which will be described later, is formed by sputtering or a method with LTO. Further, a movable contact materials Cr and Au are successively laminated by sputtering.

[0065] Then, as shown in Fig. 9A through Fig. 9C, a resist is coated, and a pattern is formed by photolithography. Subsequently, the unnecessary movable contact material is removed by etching for the formation of a movable contact 25 and a connecting base 26, and thereafter the resist is removed.

[0066] Further, as shown in Fig. 10A through Fig. 10C, a resist is coated and a pattern is formed by photolithography. Then, the insulating film is removed to expose one end of the lower electrode 22 and the upper electrode 23, and thereafter the resist is removed, thereby completing a movable contact block 10 provided with the movable piece 20.

[0067] For the fixed contact block 30 as shown in Fig. 11A through Fig. 11E, the output and input use through holes 32 and 35 and the driving use through holes 33 and 34 are formed through a glass wafer 31. Then, a recess portion 31a for ensuring an operation space and a recess portion 31b for arranging the fixed contacts 38 and 39 are successively formed. Then, a conductive ma-

terial is deposited on the recess portions 31a and 31b of the glass wafer 31, and the unnecessary conductive material is etched by photolithography, thereby forming the printed wiring lines 36 and 37. Further, by depositing a conductive material and etching the same by photolithography, the fixed contacts 38 and 39 and the connecting pads 32a (not shown), 33a, 34a and 35a are formed, thereby completing the fixed contact block 30. It is to be noted that the connecting pad 33a has a great film thickness for electrical connection to the lower electrode 22.

[0068] Finally, as shown in Fig. 2A through Fig. 2C, by placing the fixed contact block 30 on the movable contact block 10 and anodically bonding the same, the assembling is completed.

[0069] According to the present embodiment, the connecting pad 35a of the through hole 35 provided on the fixed contact block 30 is brought in pressure contact with the connecting base 26 provided on the movable contact block 10. With this arrangement, the connection between the through hole 35 and the connecting pad 35a is ensured, providing the advantage that the connection reliability improves. It is to be noted that the through hole 32 has a similar structure.

[0070] The operation of the micro-relay of this first embodiment will be described.

[0071] First, if no voltage is applied to the piezoelectric element 24, then the movable piece 20 remains flat, and the movable contact 25 is separated from the pair of fixed contacts 38 and 39.

[0072] Subsequently, if a voltage is applied to the piezoelectric element 24 via the lower electrode 22 and the upper electrode 23, then the piezoelectric element 24 is curved upward. By this operation, the movable piece 20 is curved to push up the movable contact 25, and this movable contact 25 comes in contact with the pair of fixed contacts 38 and 39, thereby making an electric circuit.

[0073] Then, if the voltage application to the piezoelectric element 24 is released, then the movable piece 20 is restored into the original state by the spring force of the thin plate-shaped substrate 21, and the movable contact 25 is separated from the fixed contacts 38 and 39.

[0074] It is to be noted that the piezoelectric element is not limited to the above-mentioned one, and it is acceptable to utilize a shape memory piezoelectric element that is deformed in the direction of thickness upon the application of voltage and retains its deformed state even when the voltage application is released.

[0075] Furthermore, with a design for obtaining the compressive stress in proximity to the critical value at which the driving starts from a silicon compound film such as a silicon oxide film or a silicon nitride film in the above embodiment, there can be provided the advantage that a large displacement can be obtained by a small input. It is to be noted that the position in which the silicon compound film is formed is not limited to the case of direct formation on the thin plate-shaped substrate, and the film may be formed in an arbitrary position.

[0076] As shown in Fig. 12A through 19, the second

embodiment is constructed so that the movable piece 20 is curved by taking advantage of the difference between the coefficient of thermal expansion of the thin plate-shaped substrate 21 and the coefficient of thermal expansion of a driving layer 28 formed on its upper surface by laminating a metal material, thereby opening and closing contacts. Therefore, the second embodiment differs from the first embodiment in that the contacts are opened and closed by taking advantage of the curving in the direction of thickness of the piezoelectric element 24 in the first embodiment.

[0077] It is to be noted that the second embodiment is assembled by anodically bonding the movable contact block 10 whose both ends are supported by the movable piece 20 with the fixed contact block 30, similar to the first embodiment.

[0078] The base 11 constituting the movable contact block 10 is similar to the aforementioned first embodiment, and therefore, no description is provided therefor.

[0079] The movable piece 20 is provided by forming a driving layer 28 by laminating a metal material via an insulating film on a heater layer 27 formed inside the surface layer of a thin plate-shaped substrate 21 and further forming a movable contact 25 via an insulating film. Then, connecting pads 27a and 27b are exposed at both end portions of the heater layer 27.

[0080] The fixed contact block 30 is provided by forming input and output use through holes 32 and 35 and driving use through holes 33 and 34 on a glass wafer 31, similar to the aforementioned first embodiment. Then, the input and output use through holes 32 and 35 are electrically connected to fixed contacts 38 and 39 via printed wiring lines 36 and 37. Further, at the lower end portions of the through holes 32, 33, 34 and 35 are formed connecting pads 32a, 33a, 34a and 35a, respectively, which are formed of a conductive material. It is to be noted that the connecting pads 32a and 35a are not shown.

[0081] Next, a manufacturing method of the micro-relay having the above construction will be described next.

[0082] It is to be noted that Fig. 13A through Fig. 19 show local sectional views showing only the important parts for the sake of convenience of explanation. Furthermore, as shown in Fig. 13A through Fig. 14D, the processes to the formation of the thin plate-shaped substrate 21 on the base 11 are similar to those of the first embodiment, and therefore, no description is provided for them.

[0083] Therefore, as shown in Fig. 15A through Fig. 15D, a resist is coated on the thin plate-shaped substrate 21 and a pattern of a portion that becomes the heater layer 27 is formed by photolithography. Further, B (Boron) ions are injected into the surface layer of the exposed thin plate-shaped substrate 21. Subsequently, the photoresist is removed, and heating is performed for activating the injected B ions and increasing the electrical resistance.

[0084] Then, as shown in Fig. 16A through Fig. 16D,

LTO (low-temperature oxide film) is laminated so as to insulate the heater layer 27. Further, a resist is coated, and a pattern for a contact hole is formed by photolithography. Subsequently, the unnecessary oxide film is removed to form the contact hole of the heater layer 27, and thereafter the resist is removed. Subsequently, a metal thin film for forming the driving layer 28 and the connecting portions 27a and 27b is laminated on its surface by sputtering.

[0085] Further, as shown in Fig. 17A through Fig. 17D, a resist is coated, and a pattern for forming the driving layer 28 and the connecting portions 27a and 27b is formed by photolithography. Then, the unnecessary metal thin film is removed by etching to form the driving layer 28 and the connecting portions 27a and 27b, and the resist is removed. Subsequently, an insulating film constructed of a low-temperature oxide film and a metal thin film formed by sputtering are successively laminated.

[0086] Subsequently, as shown in Fig. 18A through Fig. 18D, a photoresist is coated and a pattern for the movable contact 25 and the connecting base 26 is formed by photolithography. After removing the unnecessary portion of the metal thin film by etching, the resist is removed. Further, the photoresist is coated, and a pattern of a contact hole for connection to the heater layer 27 is formed by photolithography. Then, the insulating film positioned on the contact hole is removed by patterning the insulating film, thereby exposing the connecting portions 27a and 27b.

[0087] Then, by removing the photoresist as shown in Fig. 19, the movable contact block 10 that supports both ends of the movable piece 20 is completed.

[0088] On the other hand, the fixed contact block 30 is formed almost similar to the aforementioned first embodiment, and therefore, no description is provided therefor.

[0089] Finally, as shown in Fig. 12B, by placing the fixed contact block 30 on the movable contact block 10 and connecting and integrating them with each other by anodic bonding, the assembling work is completed.

[0090] According to the present embodiment, the connecting pad 35a provided at the lower end portion of the through hole 35 (not shown) comes in pressure contact with the connecting base portion 26 provided for the movable contact block 10. This arrangement ensures the connection of the through hole 35 to the printed wiring line 37 and provides the advantage that the connection reliability improves. It is to be noted that a through hole 33 has the same structure.

[0091] The operation of this second embodiment will be described.

[0092] First, if no voltage is applied to the heater layer 27, then the heater layer 27 does not generate heat. For this reason, the movable piece 20 remains flat, and the movable contact 25 is separated from the pair of fixed contacts 38 and 39.

[0093] Subsequently, if a voltage is applied to the heater layer 27 via the connecting portions 27a and 27b so

as to heat the same, the driving layer 28 is heated by the heat generation of the heater layer 27 so as to expand. This driving layer 28 has a coefficient of thermal expansion greater than that of the thin plate-shaped substrate 21. For this reason, the movable piece 20 is curved so that its upper surface becomes convex, and the movable contact 25 comes in contact with the pair of fixed contacts 38 and 39, thereby making an electric circuit.

[0094] Then, if the voltage application to the heater layer 27 is released so as to stop the heat generation, then the driving layer 28 contracts. By this operation, the movable piece 20 is restored into the original state by the spring force of the thin plate-shaped substrate 21, and the movable contact 25 separates from the fixed contacts 38 and 39.

[0095] According to the present embodiment, the coefficient of thermal expansion of the driving layer 28 that expands on the basis of the heat generation of the heater layer 27 is much larger than the coefficient of thermal expansion of the thin plate-shaped substrate 21. For this reason, the present embodiment has the advantage that the response characteristic is good and a great contact pressure force can be obtained.

[0096] As shown in Fig. 20A through 20C, the third embodiment is constructed so that a difference between the coefficient of thermal expansion of the thin plate-shaped substrate 21 and the coefficient of thermal expansion of the heater layer 27 formed inside the surface layer portion of the thin plate-shaped substrate 21 is utilized. For this reason, the third embodiment differs from the aforementioned second embodiment in that the difference between the coefficient of thermal expansion of the thin plate-shaped substrate 21 and the coefficient of thermal expansion of the driving layer 28 made of a metal material is utilized in the second embodiment. It is to be noted that an insulating film 29 is for insulating the movable contact 25 from the heater layer 27.

[0097] The manufacturing of the present embodiment is almost similar to that of the aforementioned second embodiment except for the point that the driving layer 28 made of the metal material is not provided, and therefore, no description is provided therefor.

[0098] The operation of this third embodiment will be described.

[0099] First, if no voltage is applied to the heater layer 27, then the heater layer 27 does not generate heat. Therefore, the movable piece 20 remains flat, and the movable contact 25 is separated from the pair of fixed contacts 38 and 39.

[0100] Subsequently, if a voltage is applied to the heater layer 27 via the connecting portions 27a and 27b, then the heater layer 27 generates heat. For this reason, the heater layer 27 itself expands, and the thin plate-shaped substrate 21 is expanded by being heated by this heater layer 27. However, the heater layer 27 has a coefficient of thermal expansion greater than that of the thin plate-shaped substrate 21, and therefore, the movable piece 20 is deformed so that its upper surface becomes

convex. For this reason, the movable contact 25 comes in contact with the pair of fixed contacts 38 and 39, thereby making an electric circuit.

[0101] Then, if the voltage application to the heater layer 27 is released so as to stop the heat generation of the heater layer 27, then the heater layer 27 contracts. By this operation, the movable piece 20 is restored into the original state by the spring force of the thin plate-shaped substrate 21, and the movable contact 25 separates from the fixed contacts 38 and 39.

[0102] According to the present embodiment, there is no need for providing the driving layer 28 made of the metal material in contrast to the second embodiment, and the heater layer 27 can be concurrently used as the driving layer. This arrangement has the advantage that a micro-relay having a smaller number of manufacturing processes than the second embodiment and a high productivity can be obtained.

[0103] Although the aforementioned embodiment has been described on the basis of the formation of the heater layer 27 inside the surface layer portion of the thin plate-shaped substrate 21, the present invention is not always limited to this, and it is acceptable to laminate a metal material of platinum, titanium or the like or a polysilicon on the surface of the thin plate-shaped substrate 21 for the formation of the layer.

[0104] As shown in Fig. 21, the fourth embodiment is constructed so that a cover 51 comprised of a silicon device wafer 50 is connected and integrated with the opening edge portion of a box-shaped base 41 comprised of a silicon handle wafer 40.

[0105] The aforementioned box-shaped base 41 is provided by laterally symmetrically forming connecting pads 44, printed wiring lines 45 and fixed contacts 46 on the bottom surface of a recess portion 42 in which a thermal oxidation film 43 is formed.

[0106] On the other hand, the cover 51 whose front and rear surfaces are formed with oxide films 52 and 53 are processed to have a movable piece 55 by cutting a pair of parallel slits 54 and 54. This movable piece 55 is formed with a heater section 56 constructed of a diffused resistor having a roughly bracket-like planar shape. Both ends of the heater section 56 are connected to connecting pads 57 and 57 exposed from the aforementioned oxide film 52. Further, a movable contact 58 that comes in and out of contact with the fixed contacts 46 and 46 is provided on the lower surface of the movable piece 55. Further, the cover 51 is formed with connecting use opening portions 59 and 59 in positions corresponding to the connecting pads 44 and 44.

[0107] Next, a manufacturing method of the micro-relay according to the fourth embodiment will be described with reference to Fig. 23A through Fig. 26F.

[0108] It is to be noted that the sectional views shown on the left-hand side of Fig. 23A through Fig. 26F are sectional views taken along the line 23A-23A in Fig. 22, while the sectional views shown on the right-hand side are sectional views taken along the line 23B-23B in Fig.

22.

[0109] As shown in Fig. 23A through Fig. 23J, the handle wafer 40 that becomes the box-shaped base 41 is an impurity type and has an arbitrary orientation. An alignment mark 47 is formed on the lower surface of this handle wafer 40 by wet etching or dry etching (Figs. 23C and 23D). Subsequently, the alignment mark 47 is positioned with respect to the etching mask, and the recess portion 42 is formed on the upper surface of the handle wafer 40 by wet etching or the dry etching (Figs. 23E and 23F). Further, the wafer is thermally oxidized to form an oxide film, and thereafter the thermal oxidation film located on the outer side surface and the lower surface is removed (Figs. 23G and 23H). The remaining oxide film 43 is for insulating the fixed contact 46 and facilitating the low-temperature bonding as described later. Then, the connecting pads 44, the printed wiring lines 45 and the fixed contacts 46 are formed on the upper surface of the oxide film 43 located on the bottom surface of the recess portion 42, thereby obtaining the box-shaped base 41 (Figs. 23I and 23J).

[0110] As a method for forming the fixed contact 46 and so on, it is also acceptable to use a screen printing method and a plating method other than the semiconductor processes of sputtering, deposition and so on. It is to be noted that the above-mentioned screen printing method can form a relatively thick metal film (to a thickness of about 10 μm), and this arrangement is advantageous for the formation of the fixed contact 46 and so on. It is to be noted that the screen printing method necessitates a sintering process at a temperature of about 900 °C.

[0111] As a material of the fixed contact 46 and so on, there can be enumerated, for example, the single substance of Au, Ag, Cu, Pt, Pd or Cd and the compound of these substances.

[0112] On the other hand, as shown in Fig. 24A through Fig. 24H, a p-type SOI wafer is used as the device wafer 50 for the formation of the movable piece 55. First, by injecting phosphorus ions into a thin silicon layer located on the lower surface side of the device wafer 50 and diffusing the ions until they reach the embedded insulating film 52, a heater section 56 is formed (Figs. 24C and 24D). Further, a thermal oxidation film is formed on the whole body of the device wafer 50, and therefore, the other thermal oxidation film is removed while leaving only the thermal oxidation film 53 on the lower surface (Figs. 24E and 24F). The thermal oxidation film 53 left on the lower surface is for insulating the movable contact 58 and facilitating the low-temperature bonding as described later. Then, similar to the aforementioned fixed contacts 46 and 46, a movable contact 58 is formed on the lower surface of the thermal oxidation film 53 by sputtering, deposition and so on (Fig. 24G and 24H).

[0113] Then, as shown in Fig. 25A and Fig. 25B, the device wafer 50 is connected and integrated with the box-shaped base 41.

[0114] Conventionally, the silicon objects have been

directly connected and integrated with each other at a junction temperature of about 1000°C. In contrast to this, according to the present embodiment, they are connected and integrated with each other via the thermal oxidation films 43 and 53. Therefore, they can be connected and integrated with each other at a low temperature of not higher than 450°C. For this reason, for example, the metal of Au, Ag, Pt, Pd or the like having a low melting point can be used for the contact material, and this provides the advantage that the degree of freedom of design expands.

[0115] Subsequently, the silicon located on the upper surface of the device wafer 50 is removed by an alkali etching solution of TMAH, KOH or the like. This alkali etching solution has an oxide film etching rate much smaller than the silicon etching rate. For this reason, a sandwich structure of oxide film/silicon/oxide film having high film thickness accuracy can be obtained (Figs. 25C and 25D).

[0116] Furthermore, the portion that is belonging to the insulating film 52 and is forming the connecting pads 57 and 57 is removed, thereby exposing the edge portion of the heater section 56 (Figs. 25E and 25F). Then, as shown in Fig. 26A and Fig. 26B, phosphorus is injected into the edge portion of the exposed heater section in order to obtain an ohmic contact between the heater section 56 and the connecting pads 57. Subsequently, the connecting pads 57 and 57 are formed of Al, Au or the like (Figs. 26C and 26D). Finally, the oxide film/silicon/oxide film is partially removed, and a pair of parallel slits 54 and 54 are cut, thereby forming the movable piece 55 (Figs. 26E and 26F) and forming the connecting use opening portions 59 and 59 (Fig. 21). The connecting pads 44 and 44 can be connected to the outside by wire bonding via the connecting use opening portions 59.

[0117] The operation of the micro-relay having the above-mentioned structure will be described next.

[0118] If no current is inputted to the driving use connecting pads 57 and 57, then the heater section 56 does not generate heat. Since the movable piece 55 is straight, the movable contact 58 is separated from the fixed contacts 46 and 46.

[0119] If a current is inputted to the driving use connecting pads 57 and 57, then the heater section 56 generates heat to expand the movable piece 55 by heating. By this operation, the movable piece 55 buckles to curve, and the movable contact 58 comes in contact with the fixed contacts 46 and 46.

[0120] Subsequently, if the aforementioned current input is removed, then the temperature of the movable piece 55 reduces to contract. By this operation, the movable piece 55 is restored into the original state, and the movable contact 58 separates from the fixed contacts 46 and 46.

[0121] According to the present embodiment, the heater section 56 is formed inside the movable piece 55, and the front and rear surfaces thereof are further coated with the oxide films 52 and 53, and therefore, heat loss is

small. For this reason, a micro-relay having a high response characteristic and small power consumption can be obtained.

[0122] As shown in Fig. 27, the fifth embodiment of the present invention is constructed so that the movable piece 55 has its root portion provided with a radius 55a. This arrangement has the advantage that the stress concentration is alleviated and the durability is improved.

[0123] As shown in Fig. 28 and Fig. 29, the sixth embodiment is constructed so that a cooling fin 51a is formed by dry etching on the upper surface of the cover 51 except for the movable piece 55. This arrangement provides, for example, the advantage that the interference of heat from the outside is prevented for the prevention of the occurrence of a variation in operating characteristics in the case where a number of micro-relays are arranged parallel.

[0124] It is also acceptable to provide the cooling fin 51a only on the upper surface of the movable piece 55 or provide the cooling fin 51a on the whole surface of the cover 51.

[0125] As shown in Fig. 30, the seventh embodiment is constructed so that a pair of roughly bracket-shaped slits 55b and 55b surrounding the movable contact 58 is provided for the movable piece 55 for the formation of a pair of hinge portions 55c and 55c, thereby pivotally supporting the movable contact 58.

[0126] According to the present embodiment, the movable contact 58 pivots via the hinge portions 55c and 55c when the movable contact 58 comes in contact with the fixed contacts 46 and 46. This arrangement has the advantage that the one-side hitting of the movable contact 58 against the fixed contacts 46 and 46 is eliminated, thereby improving the contact reliability.

[0127] According to the eighth embodiment, as shown in Fig. 31, the base portion of the movable piece 55 is partitioned by silicon compound portions 55d and 55e made of silicon oxide or silicon nitride. With this arrangement, according to the present embodiment, the connecting pads 57 and 57 extend over the upper surface of the silicon compound portion 55e far to the heater section 56.

[0128] In general, the heat conductivities of silicon, silicon oxide film and silicon nitride film are 1.412 W/(cmK), 0.014 W/(cmK), 0.185 W/(cmK), respectively. The heat conductivities of the silicon oxide film and the silicon nitride film are much smaller than the heat conductivity of silicon. For this reason, even if the heater section 56 of the movable piece 55 generates heat, the silicon compound portions 55d and 55e prevent heat dissipation attributed to heat conduction to the outside. As a result, there is the advantage that an energy-saving type micro-relay having an excellent response characteristic can be obtained.

[0129] As shown in Fig. 32, the ninth embodiment is constructed so that the silicon compound portions 55d and 55e are formed near the base portion of the movable piece 55. In particular, the silicon compound portion 55e located near the connecting pad 57 is discontinuous.

[0130] As shown in Fig. 33, the tenth embodiment is constructed so that the silicon layer exposed to the outside of the inside surfaces of the connecting use opening portions 59 and 59 are each coated with an insulating film 59a.

[0131] According to the present embodiment, there is the advantage that the wires bonded to the signal connecting pads 44 and 44 do not come in contact with the silicon layer of the cover 51 and are not interfered by the driving use power source.

[0132] As shown in Fig. 34, the eleventh embodiment is almost similar to the aforementioned first embodiment, and a point of difference is that the movable contacts 25 and 25 are provided on the front and rear surfaces of the movable piece 20. The other portions are almost similar to the aforementioned embodiment, and therefore, no description is provided therefor.

[0133] As shown in Fig. 35, the twelfth embodiment is almost similar to the aforementioned first embodiment. A point of difference is that the movable contact 25 is brought in contact with the fixed contacts 38 and 39 by previously curving the movable piece 20 toward the fixed contacts 38 and 39 side, for the provision of a normally-closed micro-relay.

[0134] With this arrangement, the movable contact 25 is always put in contact with the pair of fixed contacts 38 and 39 in the restored state. If the driving means is driven as in the aforementioned embodiment, then the movable piece 20 is reversely buckled against the urging force and separated from the fixed contacts 38 and 39. If the driving of the driving means is stopped, the movable piece 20 is reversely buckled by the urging force of the movable piece 20 itself, so that the movable contact 25 is restored into the original state while being brought in contact with the fixed contacts 38 and 39.

[0135] According to the present embodiment, the movable contact 25 is put in contact with the fixed contacts 38 and 39 even in an unoperated state, and therefore, an energy-saving type micro-relay having a small consumption power can be obtained.

[0136] It is also acceptable to provide the movable contact 25 on the front and rear surfaces of the movable piece 20, thereby alternately making and breaking a plurality of electric circuits.

[0137] As shown in Fig. 36, the thirteenth embodiment is constructed so that different electric circuits are alternately opened and closed by two movable contacts 25a and 25b provided on the surface of the base material 20.

[0138] That is, pivot axes 21b and 21b are coaxially provided projecting roughly from the center portion of both end portions of the thin plate-shaped substrate 21 constituting the movable piece 20, and the pivot axes 21b and 21b are integrated with the base 11.

[0139] Then, one side half 20a of the movable piece 20 is previously curved and urged so as to have a downward convex shape, while the remaining one side half 20b is previously curved and urged so as to have an upward convex shape.

[0140] Therefore, before the driving of the driving means, the movable contact 25a is separated from a pair of fixed contacts 38a and 39a, while the movable contact 25b is put in contact with a pair of fixed contacts 38b and 39b.

[0141] If the driving means is driven, then the one side half 20a of the movable piece 20 is reversely buckled so as to have an upward convex shape, so that the movable contact 25a comes in contact with the fixed contacts 38a and 39a. At the same time, the one side half 20b of the movable piece 20 is reversely buckled so as to have a downward convex shape, so that the movable contact 25b is separated from the pair of fixed contacts 38b and 39b.

[0142] Further, if the driving of the driving means is stopped, then the movable piece 20 is restored into the original state by its own spring force. By this operation, the movable contact 25a is separated from the pair of fixed contacts 38a and 39a. On the other hand, the movable contact 25b comes in contact with the fixed contacts 38b and 39b.

[0143] Although the two movable contacts 25a and 25b are arranged on the upper surface of the movable piece 20 in the present embodiment, the present invention is not always limited to this. It is also acceptable to simultaneously make and break four electric circuits by providing two movable contacts on each of the front and rear surfaces of the movable piece 20.

[0144] For the driving means of the aforementioned first embodiment through thirteenth embodiment, it is, of course, possible to select at need either the combination of the normal piezoelectric element, the shape memory piezoelectric element, the single body of the heater layer, the driving layer constructed of the heater layer and the metal material or the heater section constructed of the diffused resistor.

[0145] Furthermore, according to the aforementioned embodiments, there is no need for providing the printed wiring for the movable contact, and it is only required to form the printed wiring only for the fixed contact. For this reason, a micro-relay that has a small number of manufacturing processes and a high productivity can be obtained.

[0146] Furthermore, according to the aforementioned embodiment, there is no need for providing the printed wiring for the movable piece. Even if warp occurs in the movable piece, no disconnection of the printed wiring line occurs, ensuring a long operating life.

[0147] Then, according to the aforementioned embodiments, the contact structure becomes so-called the double-break, and this carries the advantage that the insulating property is good.

[0148] Furthermore, it is acceptable to prevent the generation of an insulating substance at the time of opening and closing the contacts by driving the movable piece in a vacuum or an environment filled with an inert gas such as neon or argon.

(First Example)

[0149] A micro-relay constructed of a movable piece that was obtained by successively laminating an oxide film having a thickness of 1.4 μm , a lower electrode having a thickness of 0.3 μm , a piezoelectric element having a thickness of 2 μm and an upper electrode having a thickness of 0.3 μm on the upper surface of the thin plate-shaped substrate having a thickness of 20 μm constructed of a silicon wafer constituting the movable piece so as to have a total thickness of 24 μm , a span of 4 mm and a width of 0.8 mm was subjected to calculation of a contact load and the amount of deformation with respect to an applied voltage. The results of calculation are shown in Fig. 37A and Fig. 37B.

[0150] According to Fig. 37A and Fig. 37B, it can be appreciated that specified contact pressure and displacement can be obtained by merely controlling the applied voltage to the piezoelectric element.

(Second Example)

[0151] A micro-relay constructed of a movable piece that was obtained by forming a heater layer having a depth of 3 μm inside the surface layer portion of the thin plate-shaped substrate having a thickness of 20 μm constructed of a silicon wafer constituting the movable piece, forming an insulative oxide film having a thickness of 1.1 μm on the upper surface of this heater layer so as to have a total thickness of 21.1 μm , a span of 4 mm and a width of 0.8 mm was subjected to calculation of a contact load and the amount of deformation with respect to an applied voltage. The results of calculation are shown in Fig. 38A and Fig. 38B.

[0152] According to Fig. 38A and Fig. 38B, it can be appreciated that specified displacement and contact pressure can be obtained by merely controlling the applied voltage for adjusting the heat generation of the heater layer.

[0153] The matrix relays of the fourteenth through seventeenth embodiments for achieving the second object will be described next with reference to the accompanying drawings of Fig. 39A through Fig. 45.

[0154] As shown in Fig. 39A and Fig. 41B, the fourteenth embodiment is a matrix relay formed by successively laminating a movable piece unit 120 and a cover 140 on a base 110 and connecting and integrating them with one another.

[0155] The base 110 is obtained by arranging parallel four shallow grooves 111, 112, 113 and 114 at a specified pitch on the upper surface of a silicon wafer 110a.

[0156] The movable piece unit 120 is obtained by arranging in an insulated state parallel first, second, third and fourth movable pieces 121, 122, 123 and 124 extended over a rectangular frame-shaped silicon wafer 120a. The first, second, third and fourth movable pieces 121, 122, 123 and 124 are formed by laminating an insulating film 126 on the upper surface of a monocrystal

thin plate-shaped substrate 125 and further successively laminating a lower electrode 127, a piezoelectric element 128 and an upper electrode 129. In the center portion of the insulating film 126 is arranged a movable contact 130 in an insulated state.

[0157] Then, by stacking the movable piece unit 120 on the base 110 and connecting and integrating them with each other, the first, second, third and fourth movable pieces 121, 122, 123 and 124 are positioned above the shallow grooves 111, 112, 113 and 114, and their both ends are fixed and supported to the opening edge portions of the base 110.

[0158] The lower electrode 127, the piezoelectric element 128 and the upper electrode 129 are illustrated as if they were separated apart by the movable contact 130 in Fig. 39B, however, the lower electrodes 127, piezoelectric elements 128 and upper electrodes 129 located on the left-hand and right-hand sides are electrically connected to the respective counterparts.

[0159] The cover 140 is formed by arranging at a specified pitch parallel deep grooves 141, 142, 143 and 144 that become the inner spaces, on the lower surface of a glass wafer 140a and providing a pair of fixed contacts 145 and 146 on the ceiling surfaces of the deep grooves 141, 142, 143 and 144 in positions corresponding to the movable contacts 130.

[0160] The fixed contacts 145 are connected to the respective through holes 161a, 162a, 163a and 164a provided on the glass wafer 140a via printed wiring lines (not shown) along the lower surface of the glass wafer 140a and led to the surface of the cover 140.

[0161] Likewise, the fixed contacts 146 are connected to the respective through holes 161b, 162b, 163b and 164b provided on the glass wafer 140a via printed wiring lines 151, 152, 153 and 154 formed along the lower surface of the glass wafer 140a and made to be electrically connectable on the surface of the cover 140.

[0162] Then, the through holes 161a and 162a are electrically connected to an input use first connecting pad 170 via a printed wiring line 155, while the through holes 163a and 164a are electrically connected to an input use second connecting pad 171 via a printed wiring line 156. Further, the through holes 161b and 163b are electrically connected to an output use first connecting pad 172 via a printed wiring line 157. The through holes 162b and 164b are electrically connected to an output use second connecting pad 173 via a printed wiring line 158.

[0163] The four lower electrodes 127 are electrically connected to a driving use common through hole 180 provided at the cover 140. On the other hand, the four upper electrodes 129 are electrically connected to driving use through holes 181, 182, 183 and 184 provided at the cover 140.

[0164] Therefore, inputs 1 and 2 and outputs 1 and 2 in the circuit diagrams of Figs. 41A and 41B correspond to the connecting pads 170 and 171 and the connecting pads 172 and 173, respectively.

[0165] Ry 1, 2, 3 and 4 in Figs. 41A and 41B correspond

to the relays constructed of the aforementioned first, second, third and fourth movable pieces 121, 122, 123 and 124, respectively.

[0166] The operation of the matrix relay having the above-mentioned construction will be described next.

[0167] First, if no voltage is applied to the lower electrode 127 of the first movable piece 121 and the upper electrode 129, then the piezoelectric element 128 is not excited, when the first movable piece 121 remains flat and the movable contact 130 is separated from the fixed contacts 145 and 146.

[0168] If a voltage is applied via the driving use common through hole 180 and the driving use through hole 181 so that the piezoelectric element 128 curves upward, then the first movable piece 121 curves upward against the spring force of the thin plate-shaped substrate 125. By this operation, the movable contact 130 comes in contact with the fixed contacts 145 and 146, and the connecting pads 170 and 172 continue each other from the through holes 161a and 161b via the printed wiring line 155 and 157.

[0169] Further, if the aforementioned voltage application is released, then the first movable piece 121 is restored into the original state by the spring force of the thin plate-shaped substrate 125, and the movable contact 130 separates from the fixed contacts 145 and 146.

[0170] Subsequently, if a voltage is applied similarly via the through holes 180 and 182 so that the piezoelectric element 128 of the second movable piece 122 curves upward, then the second movable piece 122 curves upward. By this operation, the movable contact 130 comes in contact with the fixed contacts 145 and 146, and the connecting pads 170 and 173 continue each other from the through holes 162a and 162b via the printed wiring line 155 and 158.

[0171] If a voltage is applied via the through holes 180 and 183 so that the piezoelectric element 128 of the third movable piece 123 curves upward, then the third movable piece 123 curves upward. By this operation, the movable contact 130 comes in contact with the fixed contacts 145 and 146, and the connecting pads 171 and 172 continue each other from the through holes 163a and 163b via the printed wiring line 156 and 157.

[0172] Further, if a voltage is applied via the through holes 180 and 184 so that the piezoelectric element 128 of the fourth movable piece curves upward, then the fourth movable piece 124 curves upward. By this operation, the movable contact 130 comes in contact with the fixed contacts 145 and 146, and the connecting pads 171 and 173 continue each other from the through holes 164a and 164b via the printed wiring line 156 and 158.

[0173] Although the aforementioned fourteenth embodiment has been described on the basis of the use of the normal piezoelectric element 128 that is restored into the original state upon the release of the application voltage. However, the present invention is not always limited to this, and it is acceptable to use a shape memory piezoelectric element that retains the deformed state even

when the application voltage is released and is restored into the original state when a voltage is applied in the opposite direction, for the provision of the so-called latching type matrix relay.

[0174] As shown in Fig. 42A, Fig. 42B and Fig. 43, the fifteenth embodiment is almost similar to the aforementioned first embodiment, and a point of difference is that a deformation by virtue of the thermal expansion of the first, second, third and fourth movable pieces 121, 122, 123 and 124 is utilized in contrast to the first embodiment that utilizes the deformation of the piezoelectric element 28.

[0175] That is, the first, second, third and fourth movable pieces 121, 122, 123 and 124 are constructed of a heater layer 131 whose electrical resistance is increased by injecting boron or the like into the surface of the thin plate-shaped substrate 125 made of a monocrystal and a driving layer 133 that is formed by laminating a metal material via an insulating film 132. Then, a movable contact 130 is arranged in an insulated state in the center portion of the insulating film 132.

[0176] The operation of the matrix relay of the fifteenth embodiment will be described next.

[0177] For example, as shown in Fig. 42A and 42B, if no current is flowing through the heater layer 131 of the third movable piece 123, then the heater layer 131 does not generate heat, and therefore, the driving layer 133 does not expand. For this reason, the first movable piece 121 remains flat, and the movable contact 130 thereof is separated from the fixed contacts 145 and 146.

[0178] If a current is made to flow through the heater layer 131 via the driving use common through hole 180 and the driving use through hole 183, then the heater layer 131 generates heat, thereby heating the thin plate-shaped substrate 125 and the driving layer 133. However, the coefficient of thermal expansion of the driving layer 133 is much larger than the coefficient of thermal expansion of the thin plate-shaped substrate 125, and therefore, the third movable piece 123 curves upward against the spring force of the thin plate-shaped substrate 125. By this operation, the movable contact 130 comes in contact with the fixed contacts 145 and 146. Consequently, the connecting pads 170 and 172 continue each other from the through holes 163a and 163b via the printed wiring lines 156 and 157.

[0179] Further, if the aforementioned voltage application is released, then the third movable piece 123 is restored into the original state against the spring force of the thin plate-shaped substrate 125, and the movable contact 130 separates from the fixed contacts 145 and 146.

[0180] It is to be noted that the operations of the other first, second and fourth movable pieces 121, 122 and 124 are similar to those of the fourteenth embodiment, and therefore, no description is provided for them.

[0181] Each movable piece may be formed of only the heater layer as the driving means. Furthermore, the heater layer may be formed by laminating a metal material of

platinum, titanium or the like or a polysilicon on the surface of the thin plate-shaped substrate.

[0182] Although the aforementioned embodiment has been described on the basis of the matrix relay in which the four movable pieces are arranged parallel, the present invention is not always limited to this. As shown in Fig. 44 of the sixteenth embodiment or Fig. 45 of the seventeenth embodiment, it is, of course, acceptable to apply the present invention to a matrix relay in which more than four movable pieces are arranged parallel. As a connecting method of the fixed contacts in this case, there is, for example, a connection method with a print wiring of a multilayer structure formed on the surface of the cover via through holes provided at the cover.

Claims

1. A micro-relay comprising:

a movable piece (55) comprising a thin plate-shaped substrate (21) made of a monocrystal, provided with a driving means, at least one surface of said movable piece (55) being provided with at least one movable contact (58), said movable piece (55) having two ends, fixed contacts (46) facing said at least one movable contact (58),

a base (10) supporting said movable piece (55) at said two ends so that the movable piece is arranged to be curved via said driving means thereby bringing said movable contact (58) in and out of contact with said fixed contacts (46), **characterized in that**

said at least one movable contact (58) is pivotally supported by said movable piece (55) via a pair of hinge portions (55c).

2. A micro-relay as claimed in claim 1, wherein a device wafer (50) is connected and integrated with an opening edge portion of a box-shaped base (41) comprised of a handle wafer (40) via an insulating film (52, 53), the device wafer (50) having a pair of slits (54) cut therethrough for forming the movable piece (55) therein.

3. A micro-relay as claimed in claim 2, wherein the device wafer (50) is formed with a connecting use opening portion (59) in a position opposite to a connecting pad (44) of the fixed contact provided on a bottom surface of the handle wafer (40).

4. A micro-relay as claimed in claim 3, wherein an inside surface of the connecting use opening portion (59) is covered with an insulating film (59a).

5. A micro-relay as claimed in any one of claims 2 through 4, wherein a cooling fin (51a) is formed on

an upper surface of the device wafer (50).

6. A micro-relay as claimed in any one of claims 1 through 5, wherein the movable piece (20) is previously curved and urged so as to bring the movable contact (25) provided on its one surface in contact with the fixed contacts (38, 39) that faces the movable contact. 5
7. A micro-relay as claimed in any one of claim 1 through 5, wherein a pair of pivot axes (21b) that are coaxially provided projecting roughly from a center portion between both side edge portions of the movable contact (25a, 25b) are supported on the base (10), one side half of the thin plate-shaped substrate (21) is previously curved and urged upward, the remaining side half (20b) is previously curved and urged downward and the one side halves are simultaneously reversely buckled via the driving means, thereby alternately making and breaking two electric circuits. 10 15 20
8. A micro-relay as claimed in any one of claims 1 through 7, wherein the driving means is a piezoelectric element (24) laminated on one surface of the thin plate-shaped substrate (21). 25
9. A micro-relay as claimed in any one of claims 1 through 7, wherein the driving means is a heater layer (27) formed on one surface of the thin plate shaped substrate (21). 30
10. A micro-relay as claimed in any one of claims 1 through 7, wherein the driving means is comprised of a heater layer (27) formed on one surface of the thin plate-shaped substrate (21) and a driving layer (28) formed by laminating a metal material on the heater layer (27) via an insulating film. 35
11. A micro-relay as claimed in claim 9 or 10, wherein the heater layer (27) of the driving means is comprised of a metal material such as platinum or titanium or a polysilicon laminated on the one surface of the thin plate-shaped substrate (21) via an insulating film. 40 45
12. A micro-relay as claimed in any one of claims 1 through 7, wherein the driving means is a heater section (27, 56) comprised of a diffused resistor formed inside the thin plate-shaped substrate (21). 50
13. A micro-relay as claimed in any one of claims 1 through 12, wherein an insulating film (53) is formed on at least one of a front surface or a rear surface of the movable piece (20, 51), the surface being formed with the movable contact (25, 58). 55
14. A micro-relay as claimed in any one of claims 1

through 13, wherein silicon compound films (55d, 55e) that are made of a silicon oxide film, a silicon nitride film or the like and have different thickness values are formed on the front and rear surfaces of the movable piece (55).

15. A micro-relay as claimed in any one of claims 1 through 14, wherein a silicon compound film comprised of a silicon oxide film, a silicon nitride film or the like for giving at least one side of the movable piece (20) a compressive stress in proximity to a critical value at which driving starts.
16. A micro-relay as claimed in any one of claims 1 through 15, wherein at least one adiabatic slit (55d, 55e) is formed near both end portions of the movable piece (55).
17. A micro-relay as claimed in claim 16, wherein the adiabatic slit (55d, 55e) is filled with a polymer material having low heat conductivity.
18. A micro-relay as claimed in any one of claims 1 through 17, wherein the movable piece (55) is extended across the base via an adiabatic silicon compound portion (55d, 55e) formed in both end portions of the movable piece (55).
19. A micro-relay as claimed in any one of claims 1 through 18, wherein a root portion of the movable piece (55) is provided with a radius (55a) for alleviating stress concentration.

Patentansprüche

1. Mikrorelais, welches aufweist:

ein bewegliches Teil (55), welches ein dünnes plattenförmiges Substrat (21) aus einem Monokristall, versehen mit Bewegungsmitteln, aufweist, wobei wenigstens eine Fläche des beweglichen Teils (55) mit wenigstens einem beweglichen Kontakt (58) versehen ist, wobei das bewegliche Teil (55) zwei Enden aufweist, dem wenigstens einen beweglichen Kontakt (58) zugekehrte Festkontakte (46), eine Basis (10), welche das bewegliche Teil (55) an den beiden Enden so haltert, dass das bewegliche Teil so eingerichtet ist, dass es über die Bewegungsmittel gekrümmt wird, wodurch der bewegliche Kontakt (58) in und außer Berührung mit den Festkontakten (46) gebracht wird, **dadurch gekennzeichnet, dass** der wenigstens eine bewegliche Kontakt (58) durch das bewegliche Teil (55) über ein Paar von Gelenkabschnitten (55c) schwenkbar gehalten wird.

2. Mikrorelais nach Anspruch 1, wobei ein Device-Wafer (50) über einen Isolationsfilm (52, 53) mit einem Öffnungsrandabschnitt einer kastenförmigen Basis (41) verbunden und integriert ist, die einen Substrat-Wafer (40) aufweist, wobei der Device-Wafer (50) ein Paar von Schlitzen (54) aufweist, die in diese zur Ausbildung des beweglichen Teils (55) eingeschnitten sind.
3. Mikrorelais nach Anspruch 2, wobei der Device-Wafer (50) mit einem AnschlieÖffnungsabschnitt (59) an einer Stelle gegenüber einem Anschlussfleck (44) des Festkontakts ausgebildet ist, der an einer Bodenfläche des Substratwafer (40) vorgesehen ist.
4. Mikrorelais nach Anspruch 3, wobei eine innenseitige Fläche des Verbindungsöffnungsabschnitts (59) mit einem Isolationsfilm (59a) abgedeckt ist.
5. Mikrorelais nach einem der Ansprüche 2 bis 4, wobei eine Kühlrippe (51a) an einer Oberseite des Device-Wafer (50) ausgebildet ist.
6. Mikrorelais nach einem der Ansprüche 1 bis 5, wobei das bewegliche Teil (20) vorab gekrümmt und so belastet ist, dass der auf seiner einen Seite vorgesehene bewegliche Kontakt (25) mit den Festkontakten (38, 39), die dem beweglichen Kontakt zugekehrt sind, in Berührung gebracht wird.
7. Mikrorelais nach einem der Ansprüche 1 bis 5, wobei ein Paar von Schwenkachsen (21b), die coaxial so vorgesehen sind, dass sie grob von einem Mittelabschnitt zwischen beiden Seitenrandabschnitten des Beweglichkontakts (25a, 25b) abragen, an der Basis (10) abgestützt werden, wobei eine Seitenhälfte des dünnen plattenförmigen Substrats (21) vorab gekrümmt und nach oben belastet ist, die verbleibende Seitenhälfte (20b) vorab gekrümmt und nach unten belastet ist, und die einen Seitenhälften gleichzeitig entgegengesetzt über die Bewegungsmittel verformt werden, wodurch abwechselnd zwei elektrische Kreis geschlossen und geöffnet werden.
8. Mikrorelais nach einem der Ansprüche 1 bis 7, wobei die Bewegungsmittel ein auf eine Oberfläche des dünnen plattenförmigen Substrats (21) auflaminiertes piezoelektrisches Element (24) sind.
9. Mikrorelais nach einem der Ansprüche 1 bis 7, wobei die Bewegungsmittel eine auf einer Oberfläche des dünnen plattenförmigen Substrats (21) ausgebildete Heizungsschicht (27) sind.
10. Mikrorelais nach einem der Ansprüche 1 bis 7, wobei die Bewegungsmittel aus einer auf der einen Oberfläche des dünnen plattenförmigen Substrats (21) ausgebildeten Heizungsschicht (27) und einer Bewegungsschicht (28), die durch Auflaminieren eines Metalls auf die Heizungsschicht (27) über einen Isolationsfilm ausgebildet ist, aufgebaut ist.
11. Mikrorelais nach Anspruch 9 oder 10, wobei die Heizungsschicht (27) der Bewegungsmittel aus einem Metall, wie etwa Platin oder Titan, oder einem Polysilizium, das auf der einen Oberfläche des dünnen plattenförmigen Substrats (21) über einen Isolationsfilm auflaminiert ist, aufgebaut ist.
12. Mikrorelais nach einem der Ansprüche 1 bis 7, wobei die Bewegungsmittel ein Heizungsabschnitt (27, 56) sind, der aus einem verteilten Widerstand, der innerhalb des dünnen plattenförmigen Substrats (21) ausgebildet ist, aufgebaut ist.
13. Mikrorelais nach einem der Ansprüche 1 bis 12, wobei ein Isolationsfilm (53) auf wenigstens einer von Vorderfläche oder Rückfläche des beweglichen Teils (20, 51) ausgebildet ist, wobei die Fläche mit dem Beweglichkontakt (25, 58) ausgebildet ist.
14. Mikrorelais nach einem der Ansprüche 1 bis 13, wobei Siliziumverbindungsfilme (25d, 25e), die aus einem Siliziumoxidfilm, einem Siliziumnitridfilm oder dgl. bestehen und unterschiedliche Dickenwerte haben, auf Vorder- und Rückfläche des beweglichen Teils (55) ausgebildet sind.
15. Mikrorelais nach einem der Ansprüche 1 bis 14, wobei ein Siliziumverbindungsfilm aus einem Siliziumoxidfilm, einen Siliziumnitridfilm oder dgl. so aufgebaut ist, dass wenigstens eine Seite des beweglichen Teils (20) eine Kompressionsspannung in der Nähe eines kritischen Werts, bei welchem das Bewegen beginnt, erhält.
16. Mikrorelais nach einem der Ansprüche 1 bis 15, bei welchem wenigstens ein adiabatischer Schlitz (55d, 55e) in der Nähe beider Endabschnitte des beweglichen Teils (55) ausgebildet ist.
17. Mikrorelais nach Anspruch 16, wobei der adiabatische Schlitz (55d, 55e) mit einem Polymermaterial mit niedriger Wärmeleitfähigkeit gefüllt ist.
18. Mikrorelais nach einem der Ansprüche 1 bis 17, wobei sich das bewegliche Teil (55) über die Basis hinweg über einen Abschnitt (55d, 55e) mit adiabatischer Siliziumverbindung erstreckt, der an beiden Endabschnitten des beweglichen Teils (55) ausgebildet ist.
19. Mikrorelais nach einem der Ansprüche 1 bis 18, wobei ein Fußabschnitt des beweglichen Teils (55) mit einem Radius (55a) zur Milderung von Spannungs-konzentration vorgesehen ist.

Revendications

1. Micro-relais comprenant :

une pièce mobile (55) comprenant un substrat en forme de plaque fine (21) constitué d'un monocristal, fournie avec un moyen d'entraînement, au moins une surface de ladite pièce mobile (55) étant fournie avec au moins un contact mobile (58), ladite pièce mobile (55) ayant deux extrémités, des contacts fixes (46) faisant face au dit au moins un contact mobile (58), une base (10) supportant ladite pièce mobile (55) aux dites deux extrémités de manière à ce que la pièce mobile soit agencée pour être incurvée par l'intermédiaire dudit moyen d'entraînement ce qui met ledit contact mobile (58) en contact et hors contact avec lesdits contacts fixes (46), **caractérisé en ce que :**

ledit au moins un contact mobile (58) est supporté en pivot par ladite pièce mobile (55) par l'intermédiaire d'une paire de portions de charnière (55c).

2. Micro-relais selon la revendication 1, dans lequel une tranche de dispositif (50) est connectée et intégrée à une portion de bord d'ouverture d'une base en forme de boîte (41) composée d'une tranche de poignée (40) par l'intermédiaire d'une pellicule d'isolation (52, 53), la tranche de dispositif (50) ayant une paire de fentes (54) découpées à travers celle-ci pour former la pièce mobile (55) à l'intérieur de celle-ci.

3. Micro-relais selon la revendication 2, dans lequel la tranche de dispositif (50) est formée avec une portion d'ouverture à usage de connexion (59) dans une position opposée à un tampon de connexion (44) du contact fixe fourni sur une surface basse de la tranche de poignée (40) .

4. Micro-relais selon la revendication 3, dans lequel une surface intérieure de la portion d'ouverture à usage de connexion (59) est recouverte d'une pellicule d'isolation (59a) .

5. Micro-relais selon l'une quelconque des revendications 2 à 4, dans lequel une ailette de refroidissement (51a) est formée sur une surface supérieure de la tranche de dispositif (50).

6. Micro-relais selon l'une quelconque des revendications 1 à 5, dans lequel la pièce mobile (20) est précédemment incurvée et amenée à mettre le contact mobile (25) fourni sur sa surface en contact avec les contacts fixes (38, 39) faisant face au contact mobile.

7. Micro-relais selon l'une quelconque des revendications 1 à 5, dans lequel une paire d'axes pivotants (21b) qui sont fournis de manière coaxiale en se projetant globalement à partir d'une portion centrale entre les deux portions de bord latérales du contact mobile (25a, 25b) sont supportés sur la base (10), une moitié de côté du substrat en forme de plaque fine (21) est précédemment incurvée et amenée vers le haut, l'autre moitié de côté (20b) est précédemment incurvée et amenée vers le bas et les moitiés d'un même côté sont simultanément attachées inversement par l'intermédiaire du moyen d'entraînement, ce qui ouvre et ferme alternativement deux circuits électriques.

8. Micro-relais selon l'une quelconque des revendications 1 à 7, dans lequel le moyen d'entraînement est un élément piézoélectrique (24) stratifié sur une surface du substrat en forme de plaque fine (21) .

9. Micro-relais selon l'une quelconque des revendications 1 à 7, dans lequel le moyen d'entraînement est une couche de chauffage (27) formée sur une surface du substrat en forme de plaque fine (21).

10. Micro-relais selon l'une quelconque des revendications 1 à 7, dans lequel le moyen d'entraînement se compose d'une couche de chauffage (27) formée sur une surface du substrat en forme de plaque fine (21) et d'une couche d'entraînement (28) formée en stratifiant un matériau métallique sur la couche de chauffage (27) par l'intermédiaire d'une pellicule d'isolation.

11. Micro-relais selon la revendication 9 ou 10, dans lequel la couche de chauffage (27) du moyen d'entraînement se compose d'un matériau métallique comme du platine ou du titane ou d'un poly-silicium stratifié sur la surface du substrat en forme de plaque fine (21) par l'intermédiaire d'une pellicule d'isolation.

12. Micro-relais selon l'une quelconque des revendications 1 à 7, dans lequel le moyen d'entraînement est une section de chauffage (27, 56) composée d'une résistance diffusée formée à l'intérieur du substrat en forme de plaque fine (21) .

13. Micro-relais selon l'une quelconque des revendications 1 à 12, dans lequel une pellicule d'isolation (53) est formée sur au moins l'une d'une surface avant ou d'une surface arrière de la pièce mobile (20, 51), la surface étant formée du contact mobile (25, 58) .

14. Micro-relais selon l'une quelconque des revendications 1 à 13, dans lequel des pellicules de composé de silicium (55d, 55e) constituées d'une pellicule d'oxyde de silicium, d'une pellicule de nitrure de si-

licium ou d'une pellicule similaire et ayant des valeurs d'épaisseur différentes sont formées sur les surfaces avant et arrière de la pièce mobile (55).

15. Micro-relais selon l'une quelconque des revendications 1 à 14, dans lequel une pellicule de composé de silicium est constituée d'une pellicule d'oxyde de silicium, d'une pellicule de nitrure de silicium ou d'une pellicule similaire pour donner à au moins un côté de la pièce mobile (20) une tension de compression à proximité d'une valeur critique à laquelle l'entraînement commence. 5
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16. Micro-relais selon l'une quelconque des revendications 1 à 15, dans lequel au moins une fente adiabatique (55d, 55e) est formée à proximité des deux portions d'extrémité de la pièce mobile (55). 15
17. Micro-relais selon la revendication 16, dans lequel la fente adiabatique (55d, 55e) est remplie d'un matériau polymère ayant une faible conductivité thermique. 20
18. Micro-relais selon l'une quelconque des revendications 1 à 17, dans lequel la pièce mobile (55) est étendue à travers la base par l'intermédiaire d'une portion adiabatique de composé de silicium (55d, 55e) formée dans les deux portions d'extrémité de la pièce mobile (55) . 25
30
19. Micro-relais selon l'une quelconque des revendications 1 à 18, dans lequel une portion de racine de la pièce mobile (55) est fournie avec un rayon (55a) pour atténuer la concentration de tension. 35

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Fig. 1

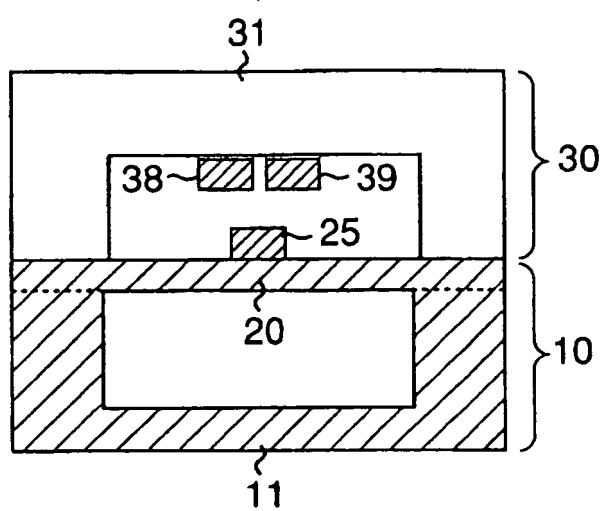


Fig.2A

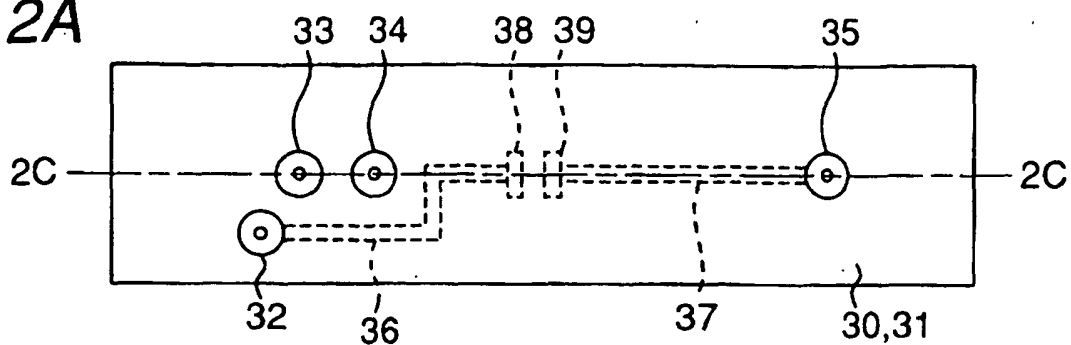


Fig.2B

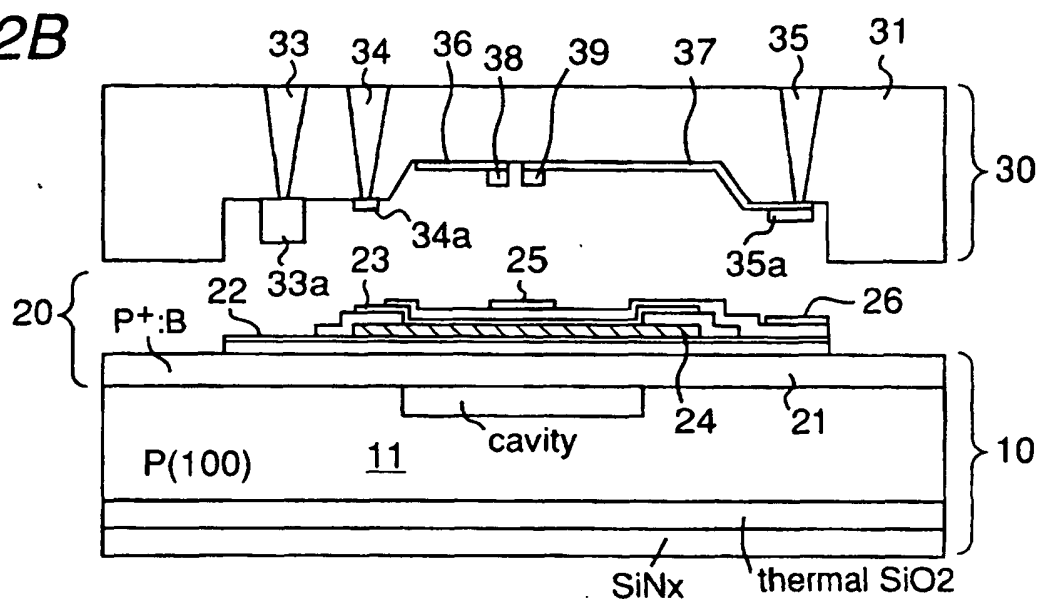


Fig.2C

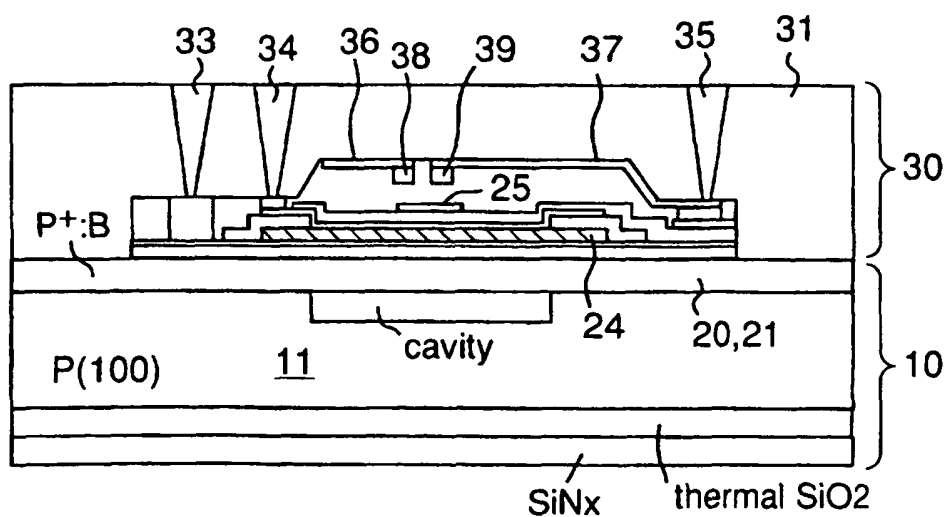


Fig.3A

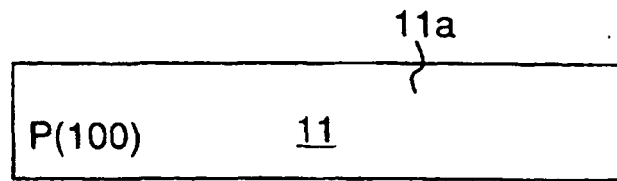


Fig.3B

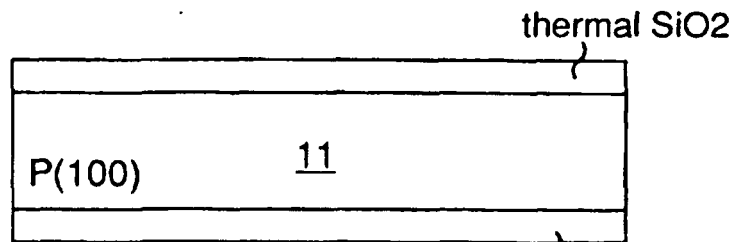


Fig.3C

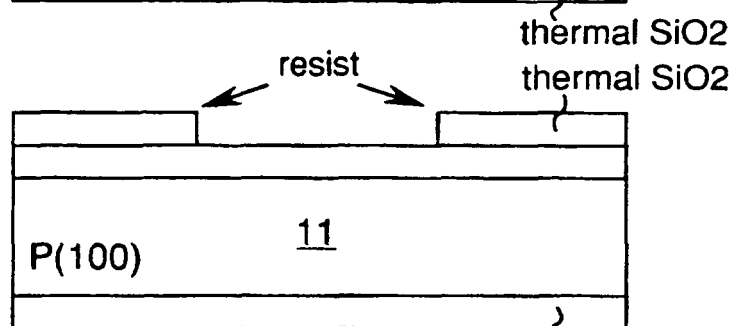


Fig.3D

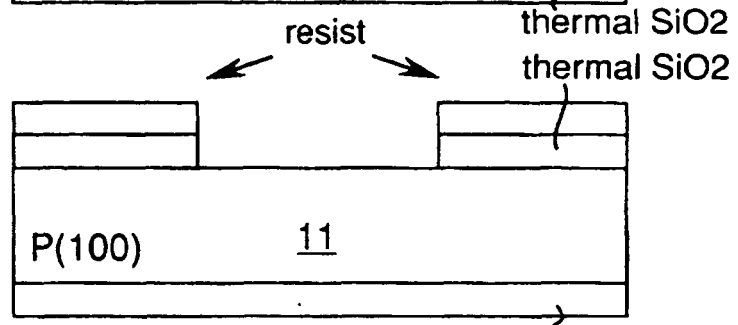


Fig.3E

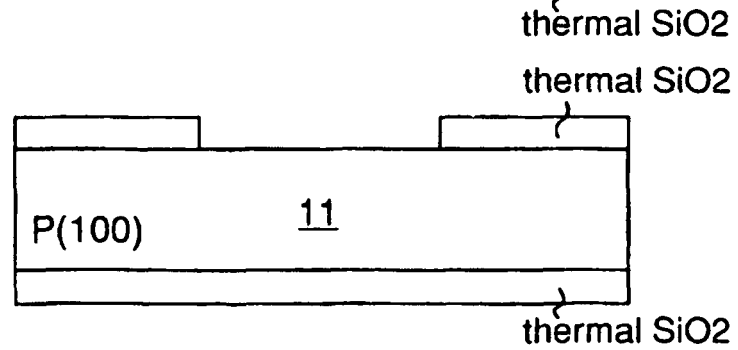


Fig.4A

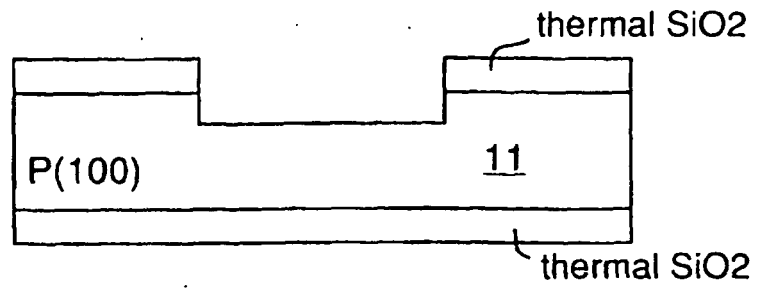


Fig.4B

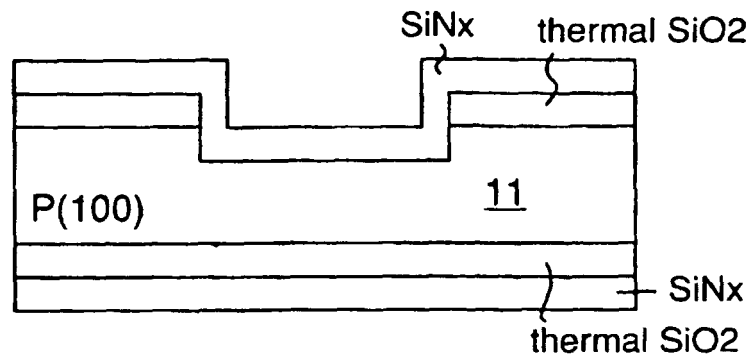


Fig.4C

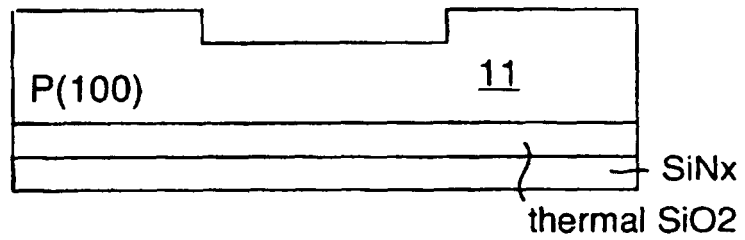
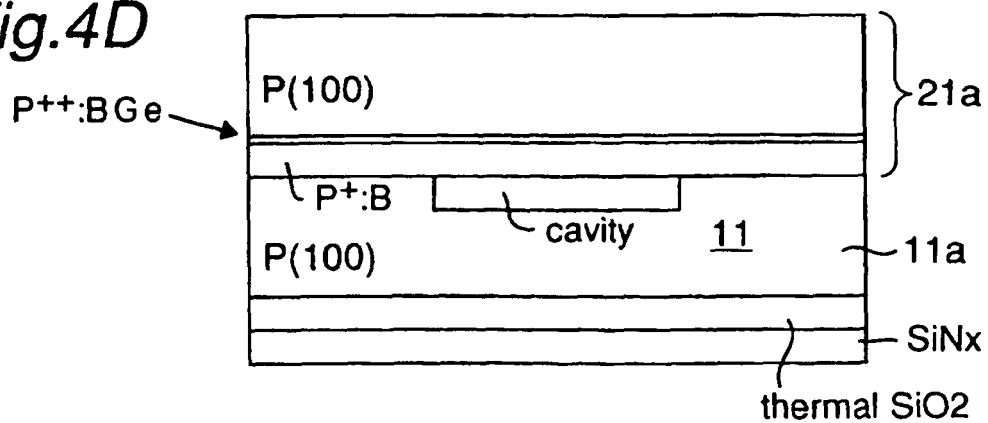


Fig.4D



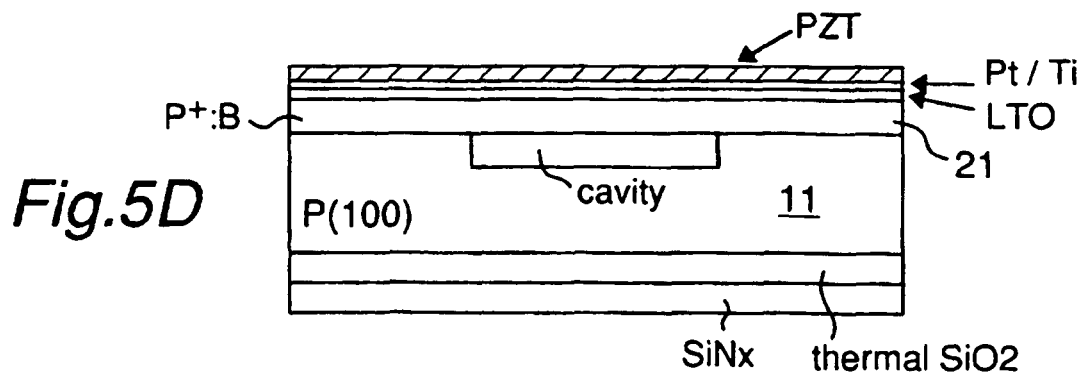
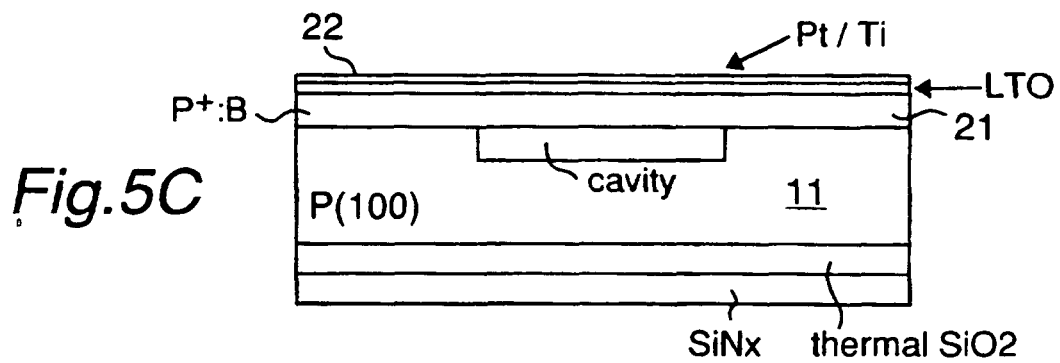
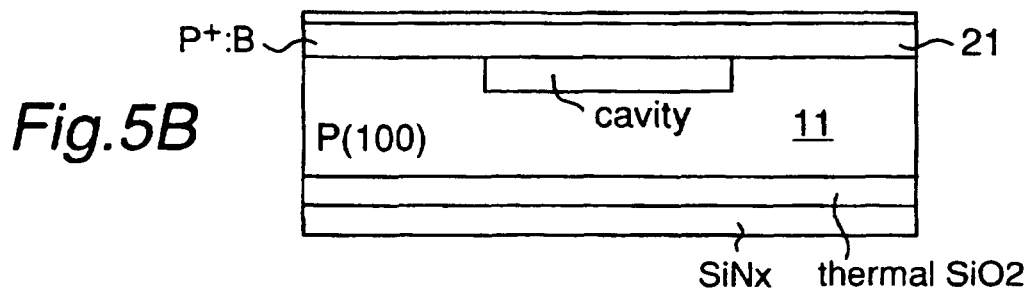
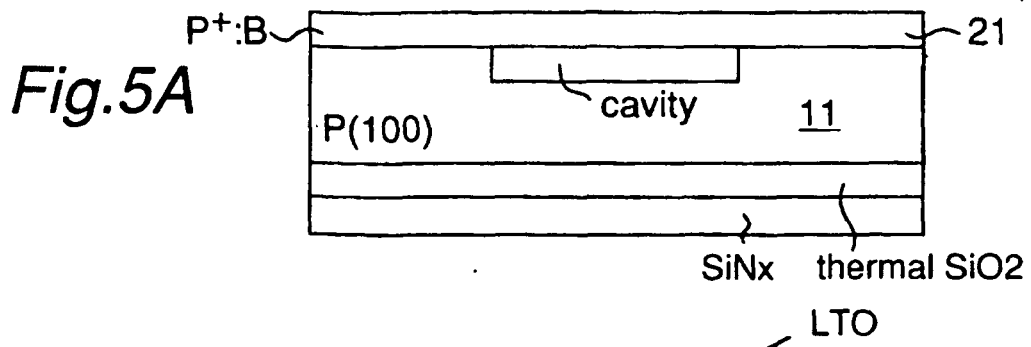
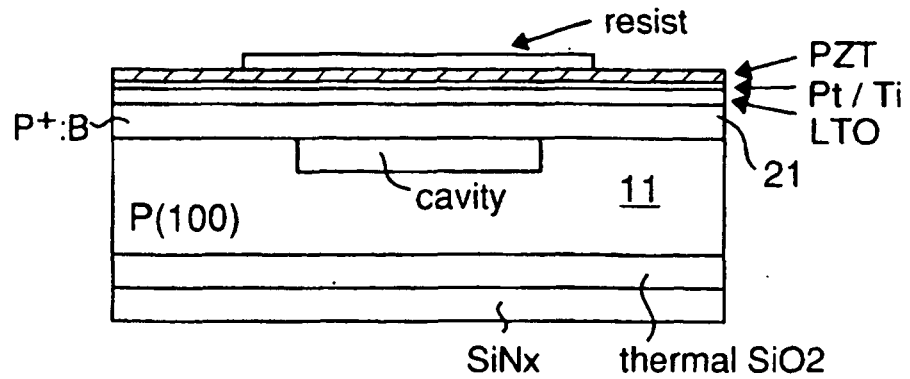
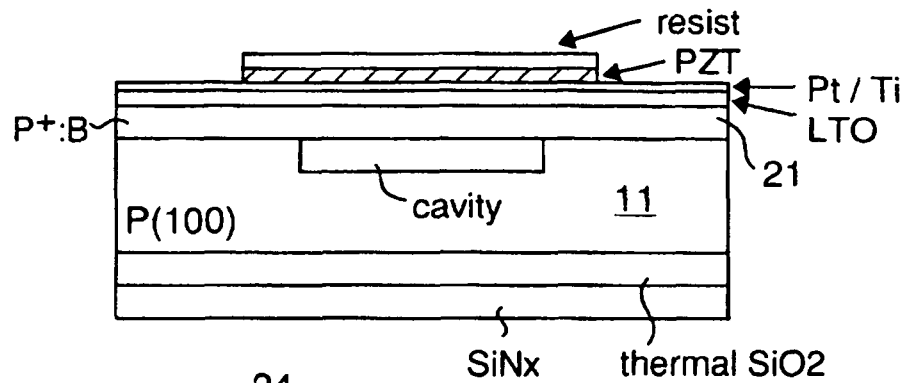
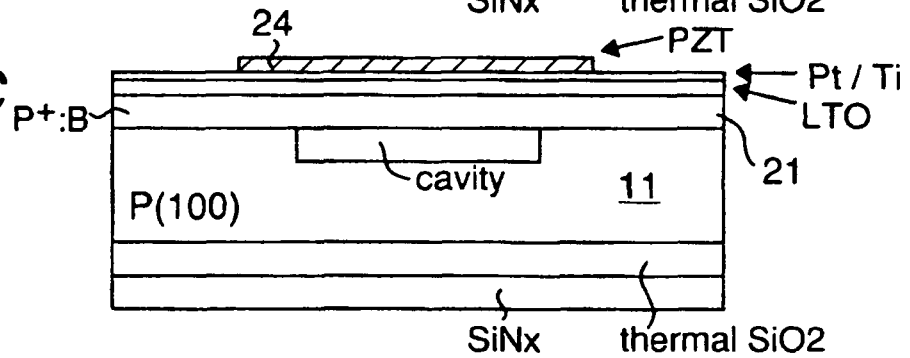
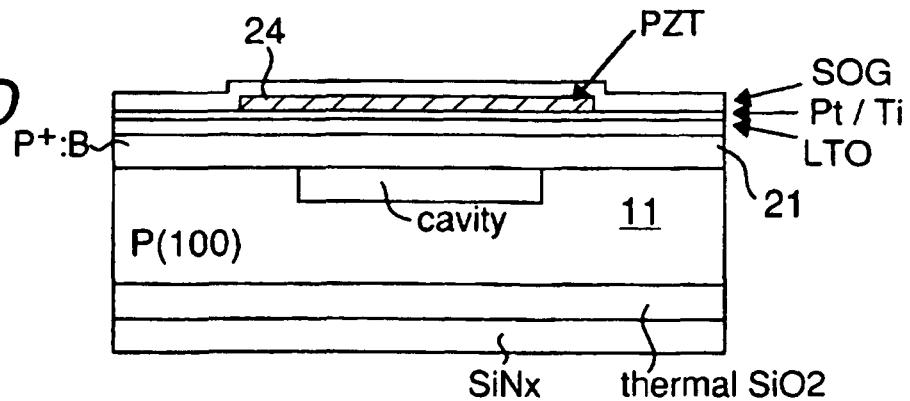
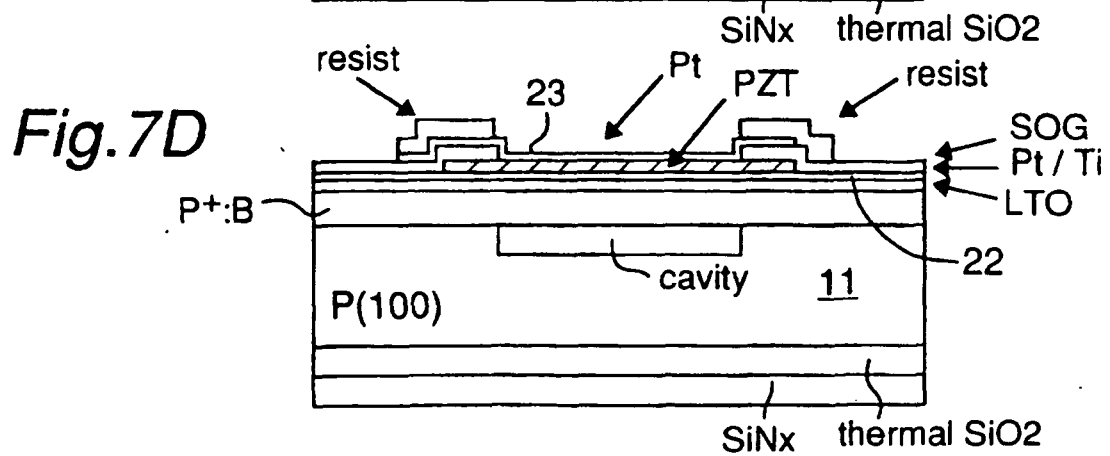
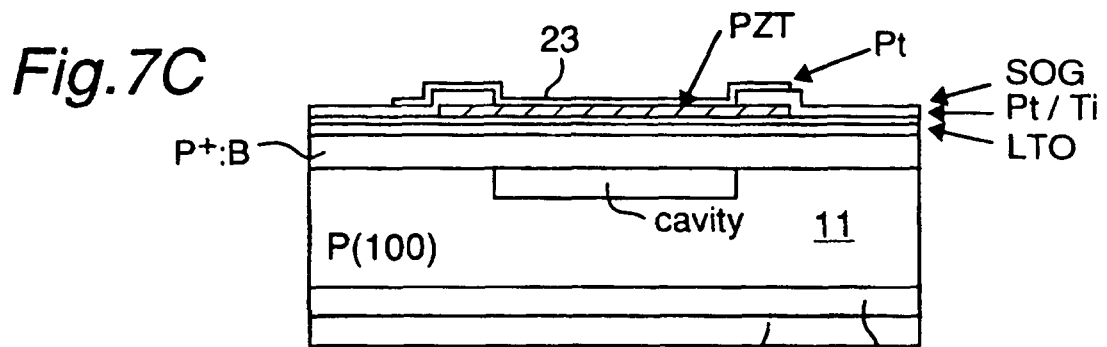
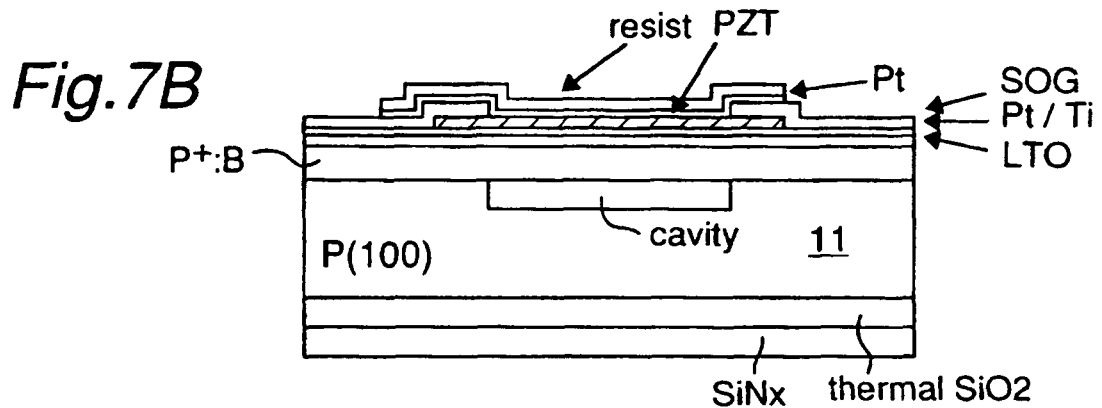
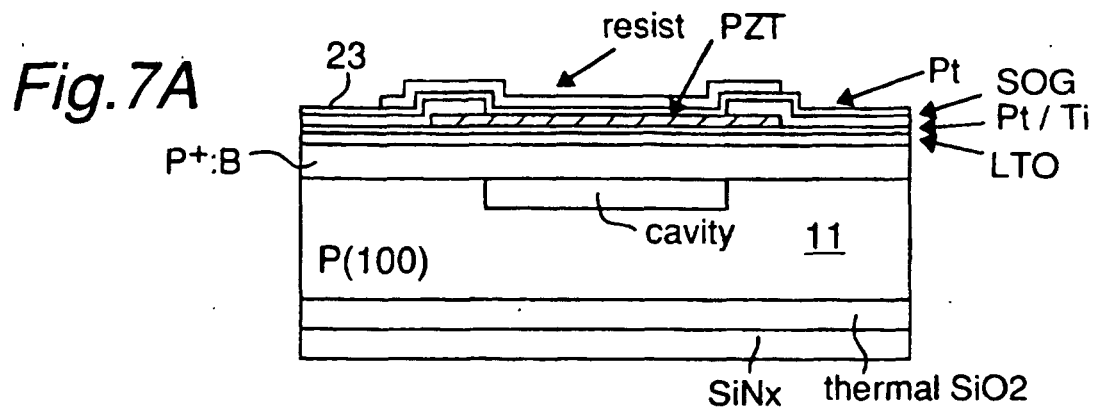


Fig.6A*Fig.6B**Fig.6C**Fig.6D*



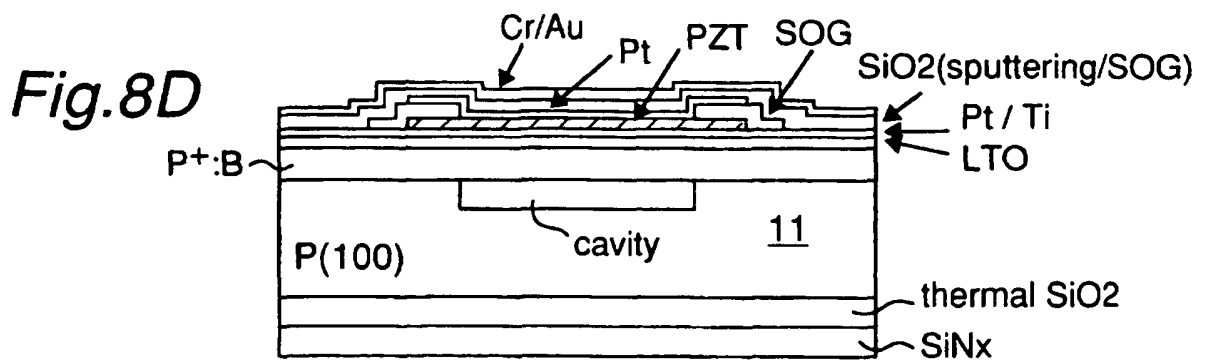
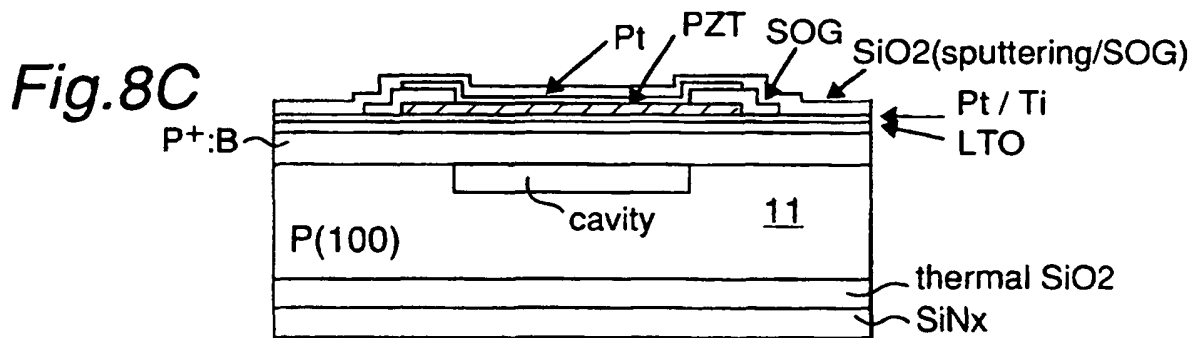
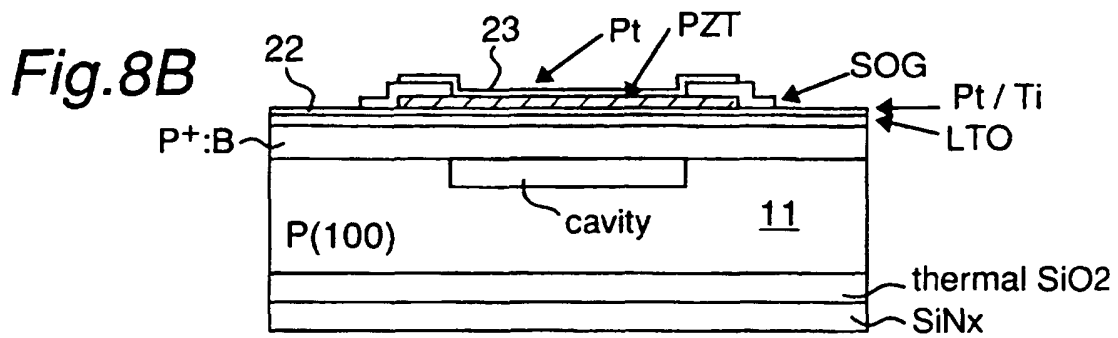
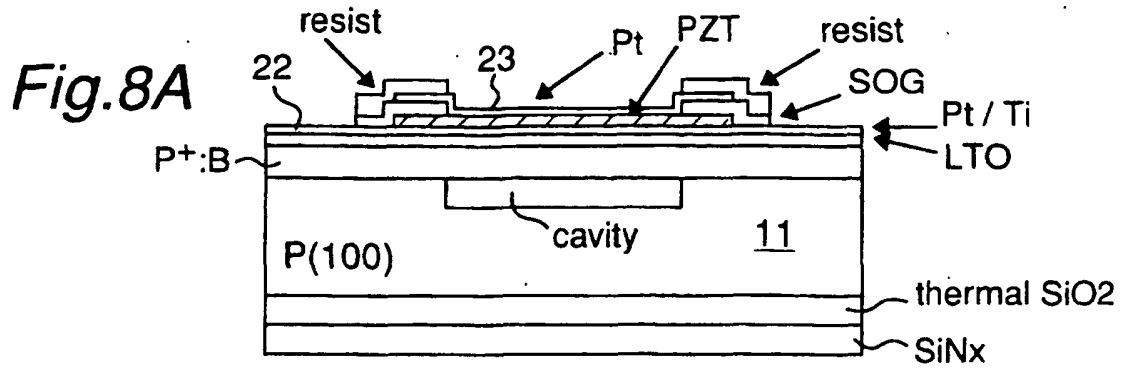


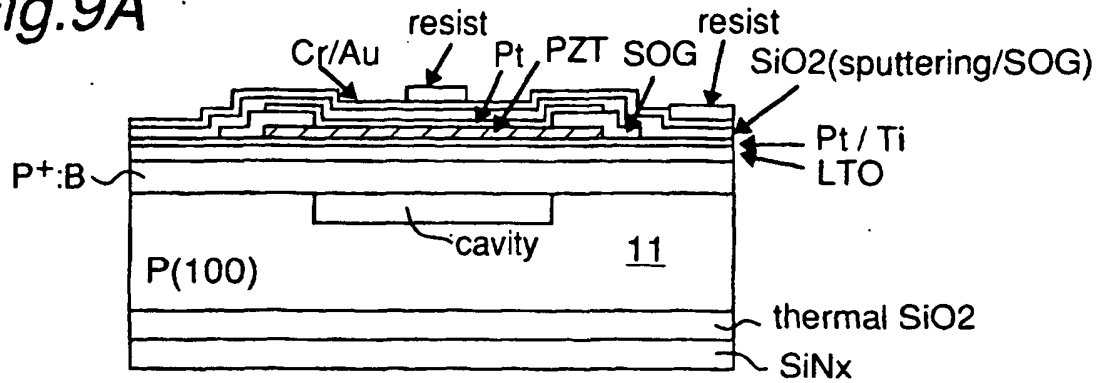
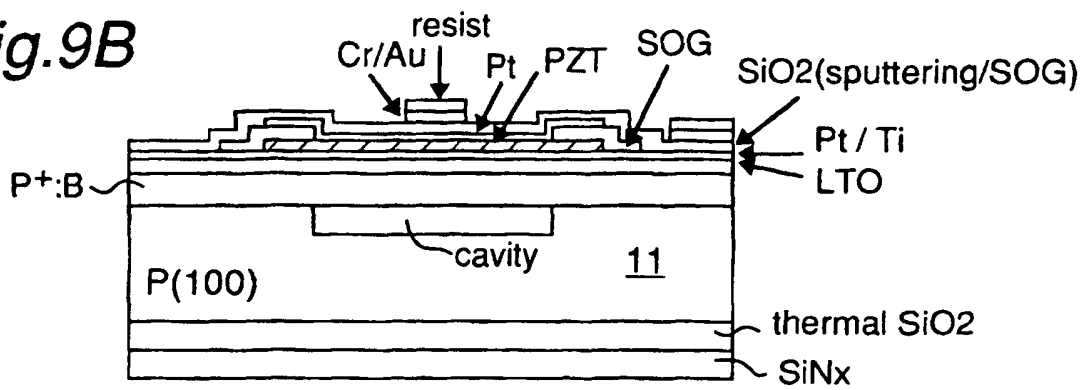
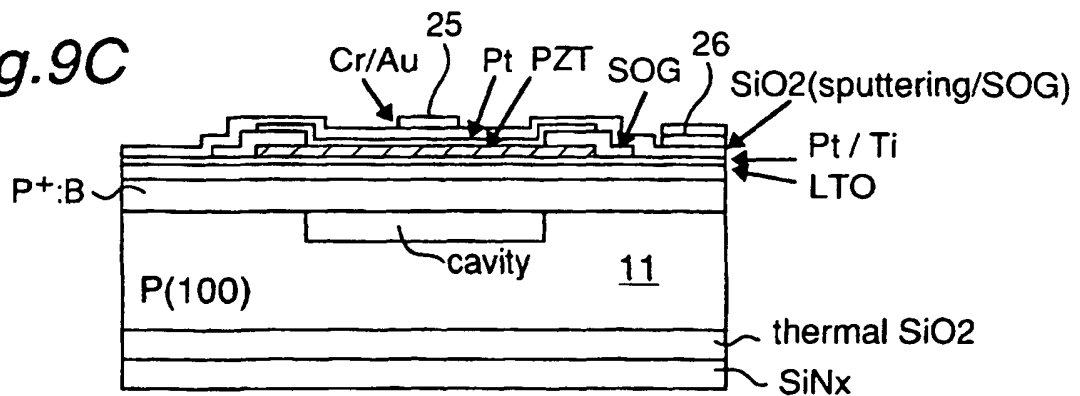
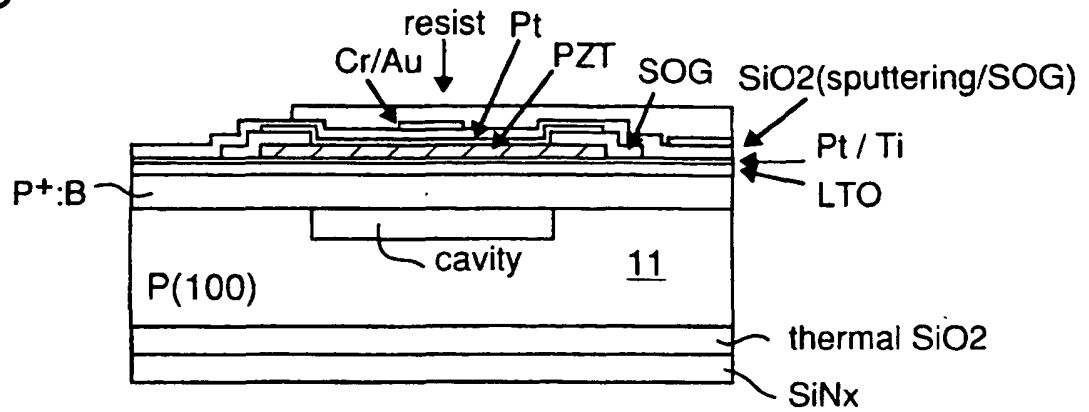
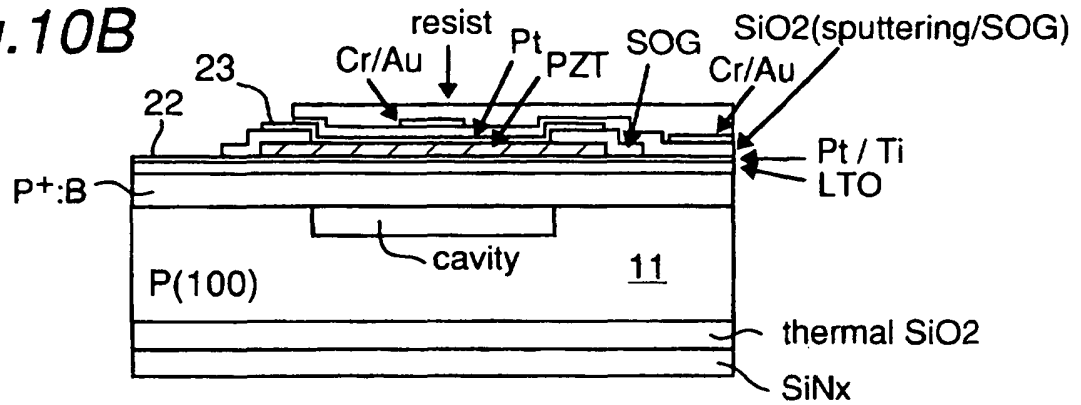
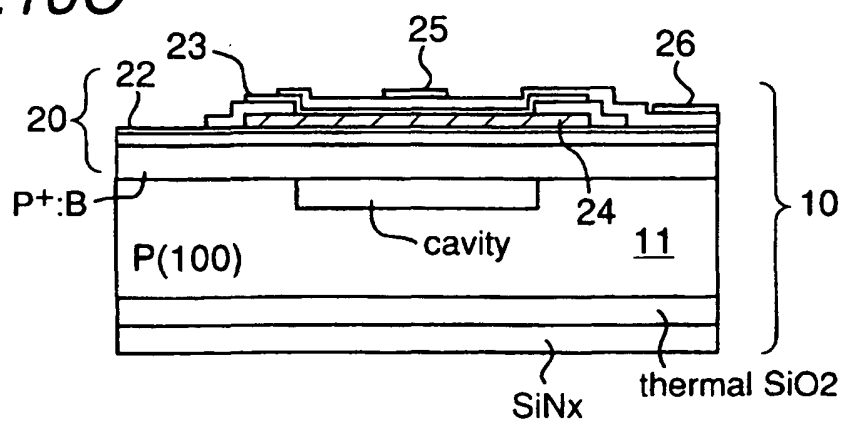
Fig.9A*Fig.9B**Fig.9C*

Fig.10A*Fig.10B**Fig.10C*

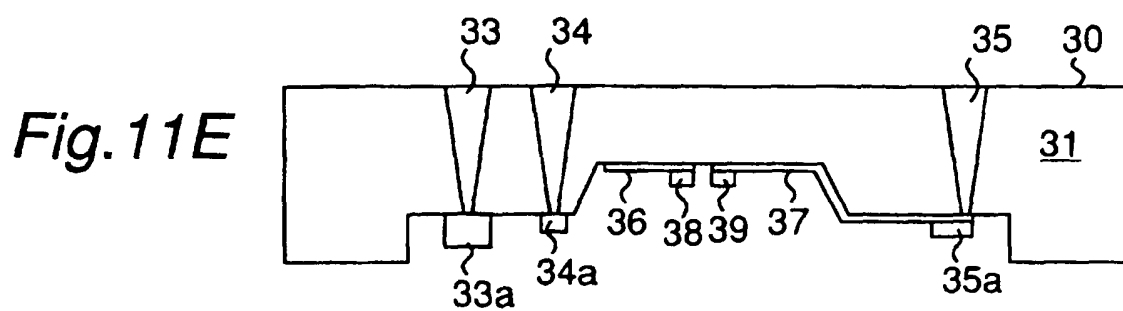
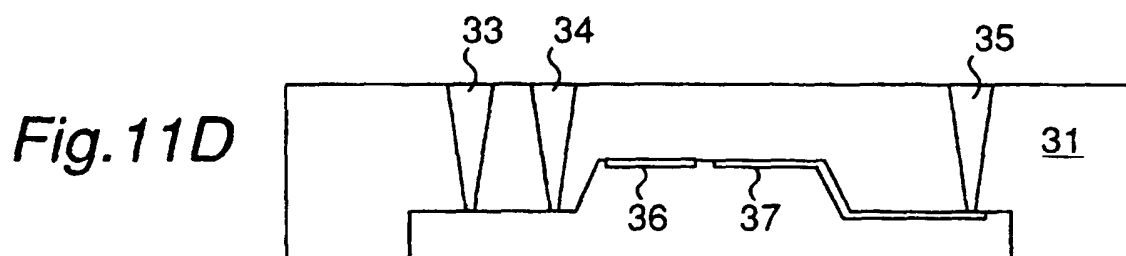
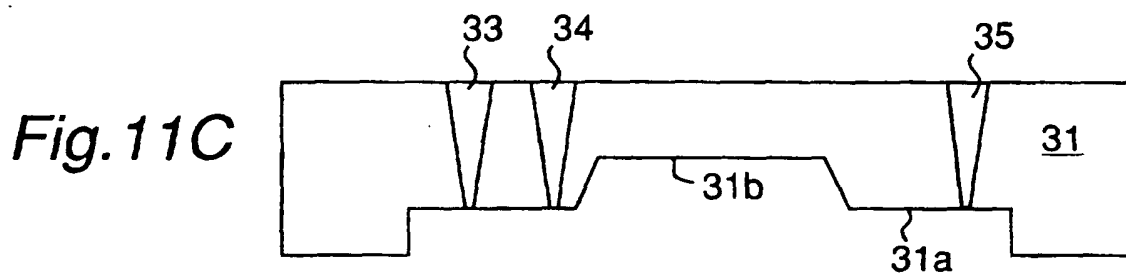
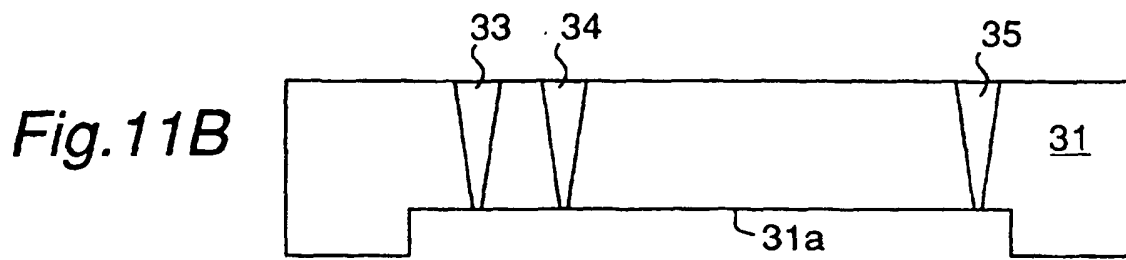
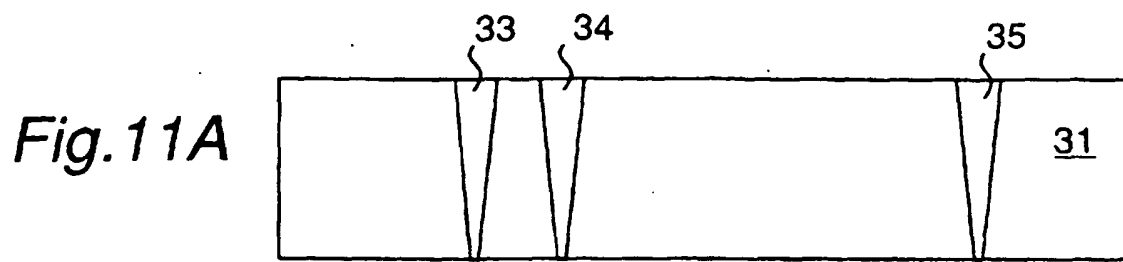


Fig. 12A

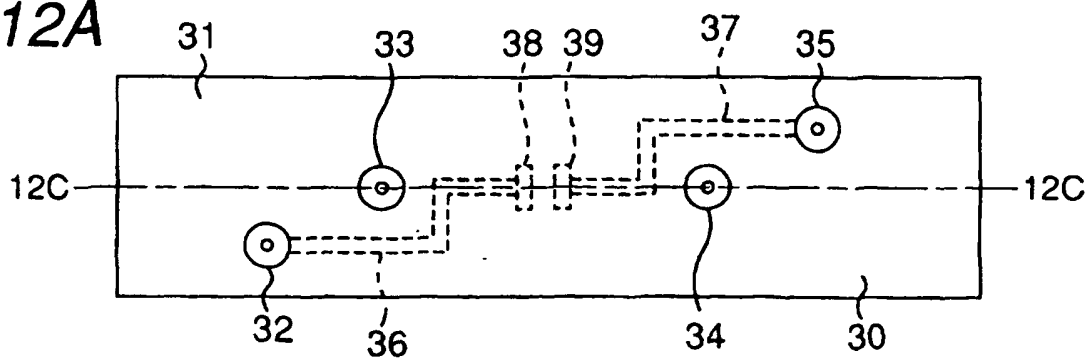


Fig. 12B

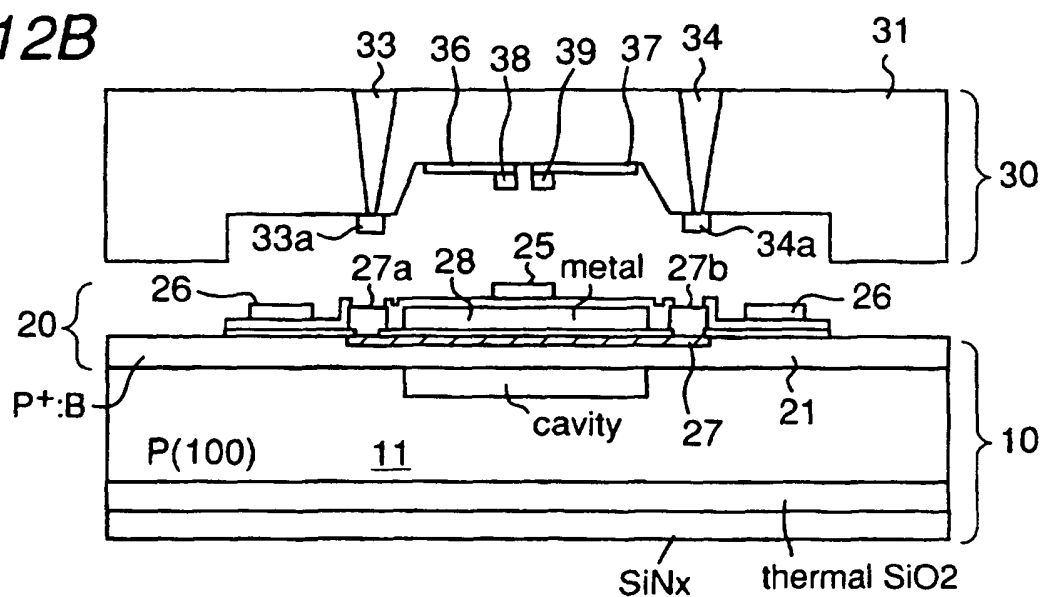


Fig. 12C

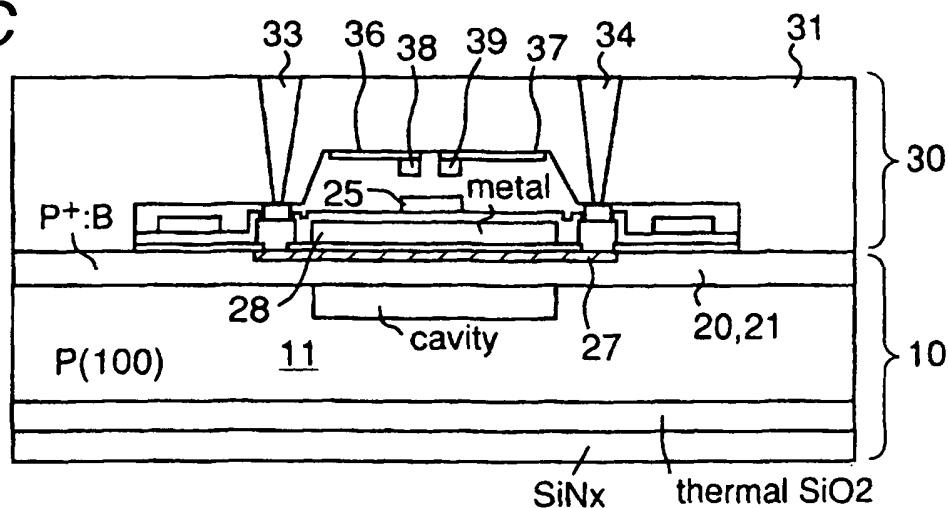


Fig.13A

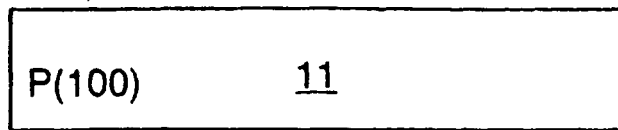


Fig.13B

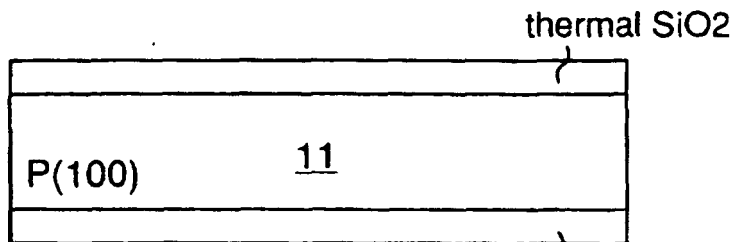


Fig.13C

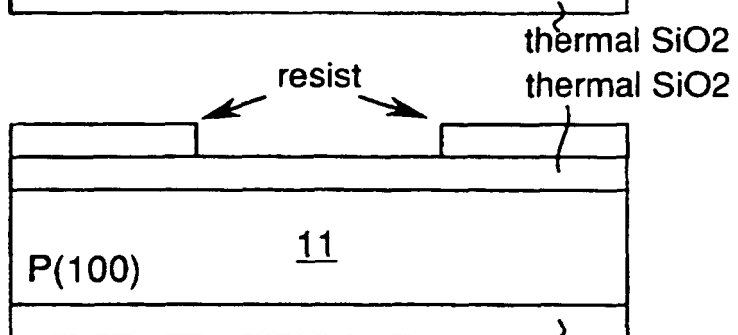


Fig.13D

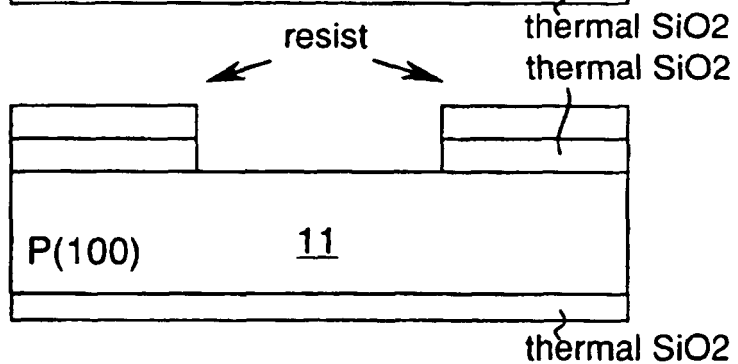


Fig.13E

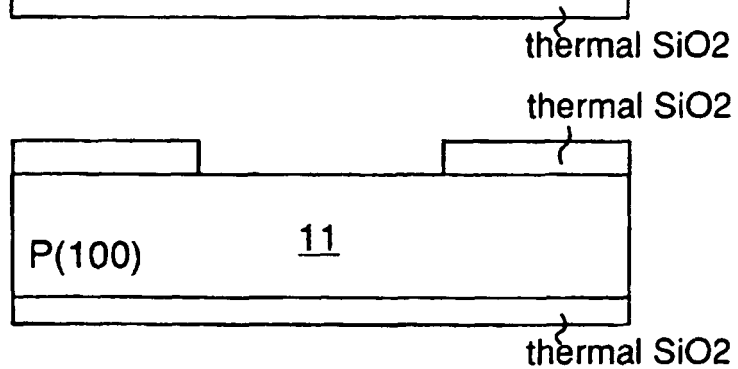


Fig.14A

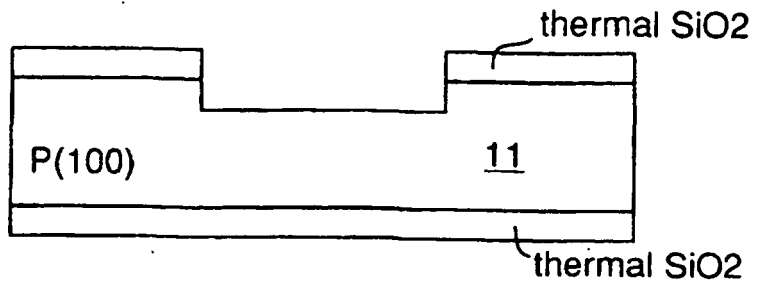


Fig.14B

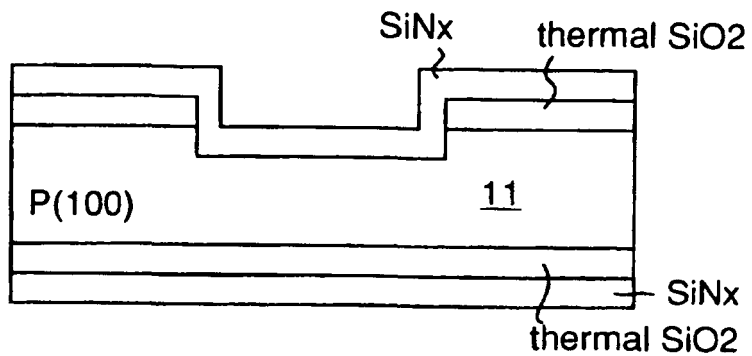


Fig.14C

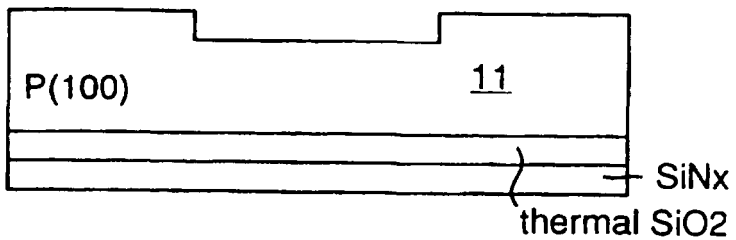


Fig.14D

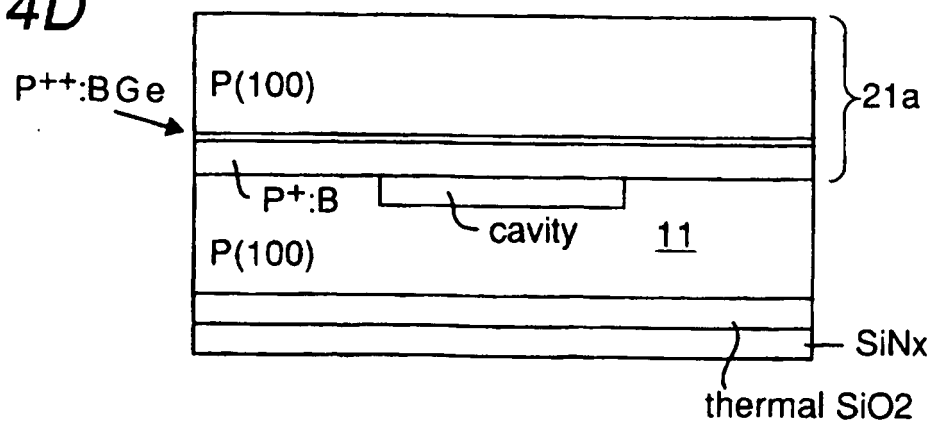


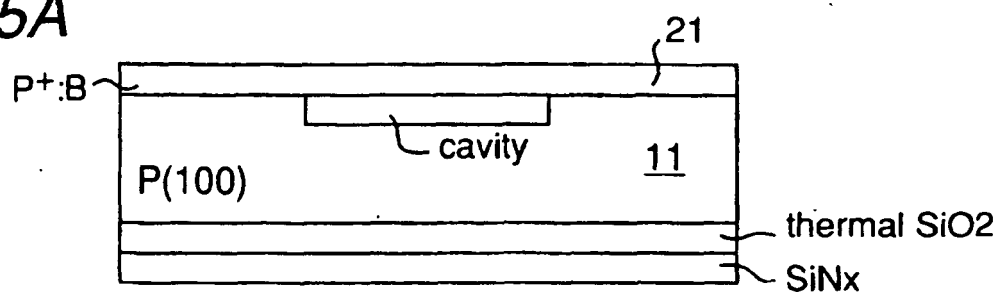
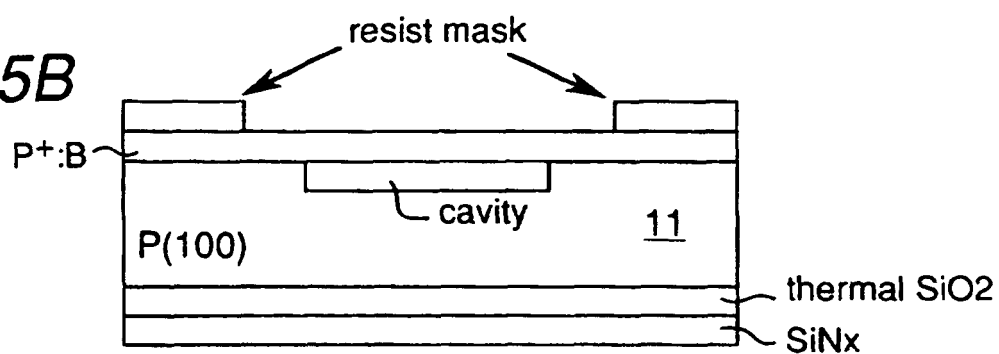
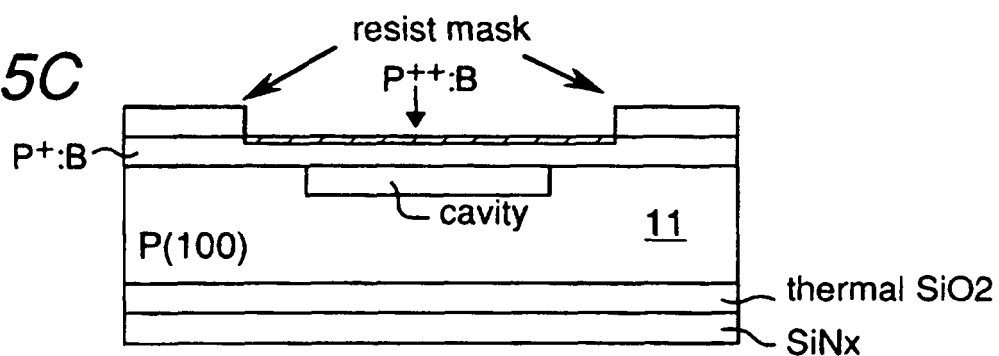
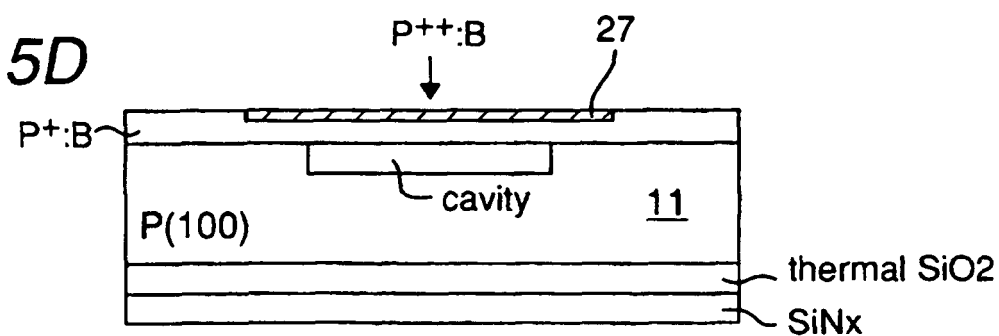
Fig. 15A*Fig. 15B**Fig. 15C**Fig. 15D*

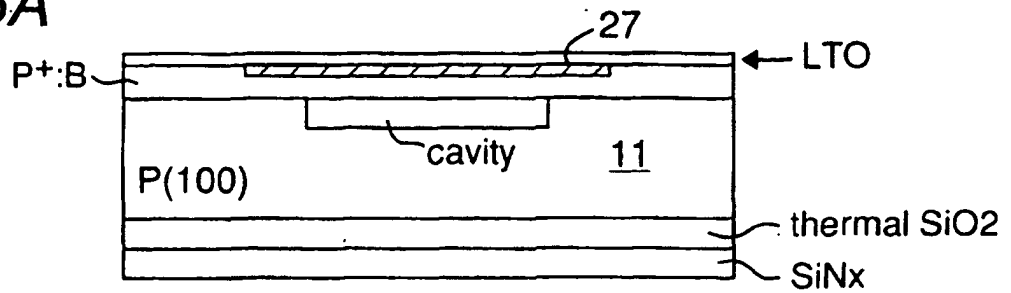
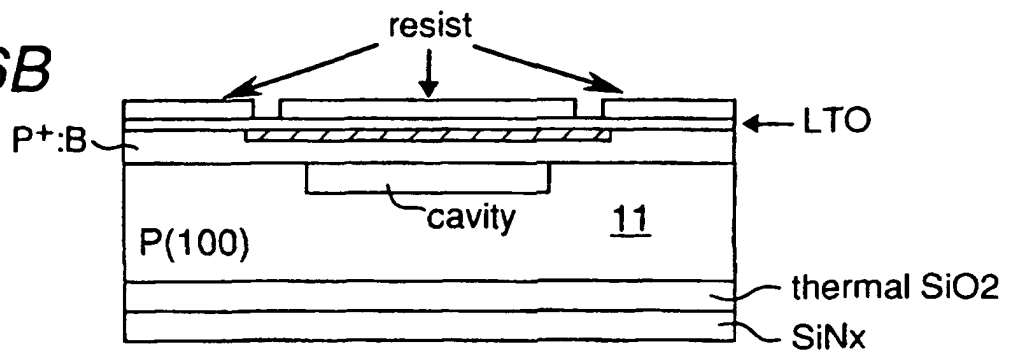
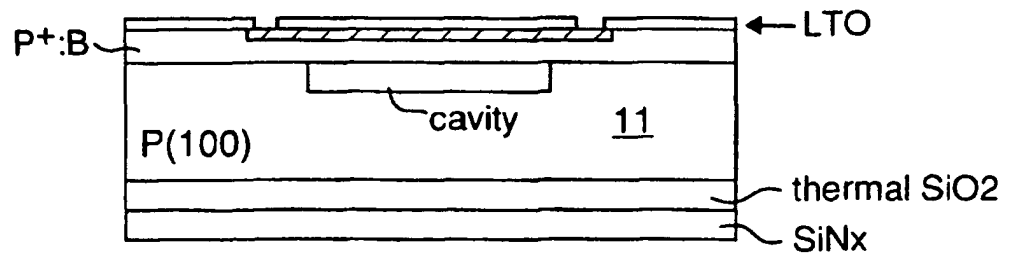
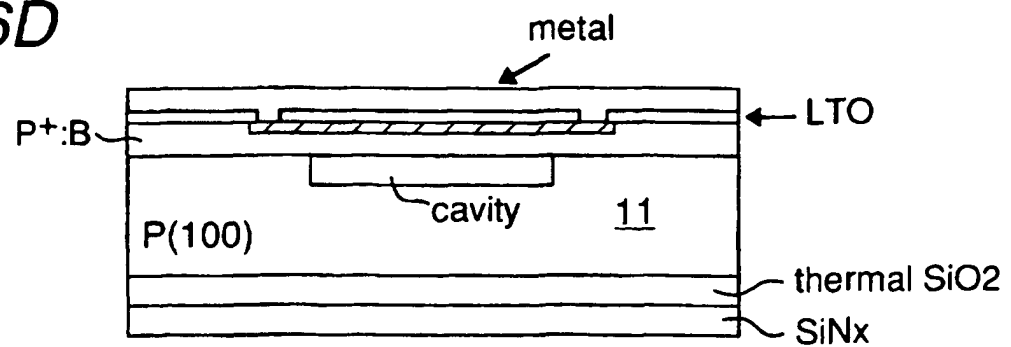
Fig. 16A*Fig. 16B**Fig. 16C**Fig. 16D*

Fig.17A

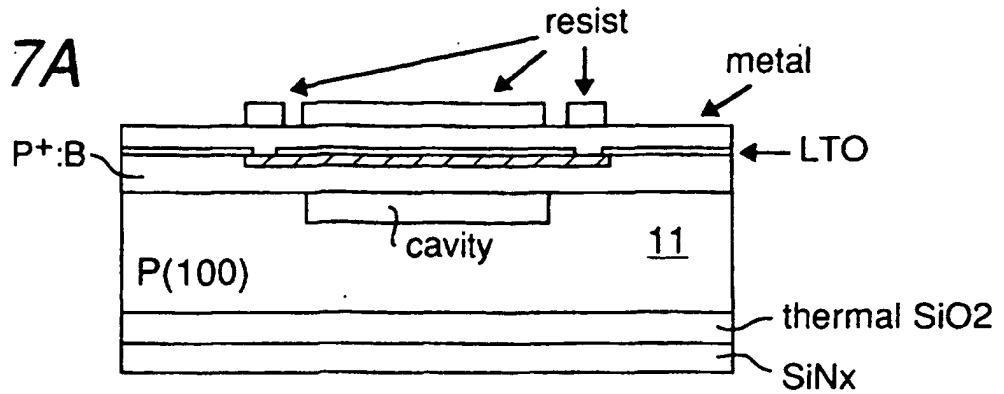


Fig.17B

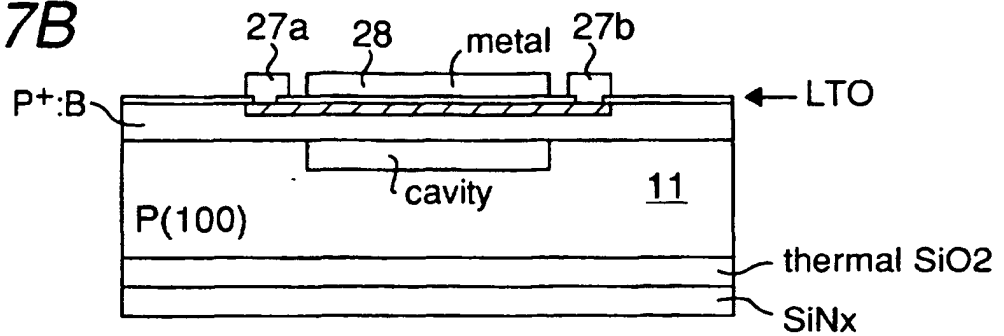


Fig.17C

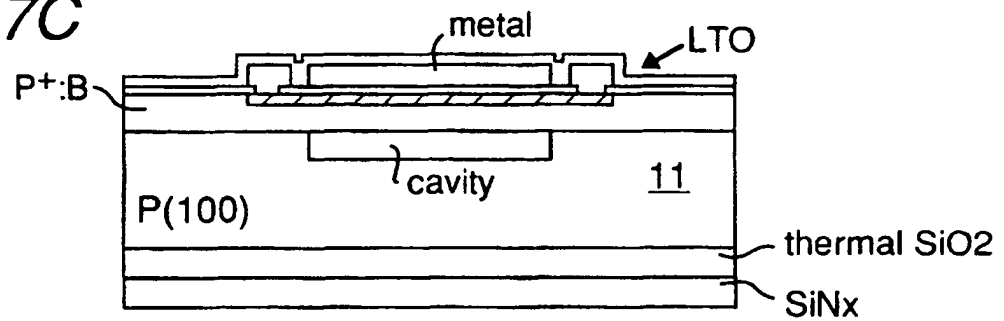


Fig.17D

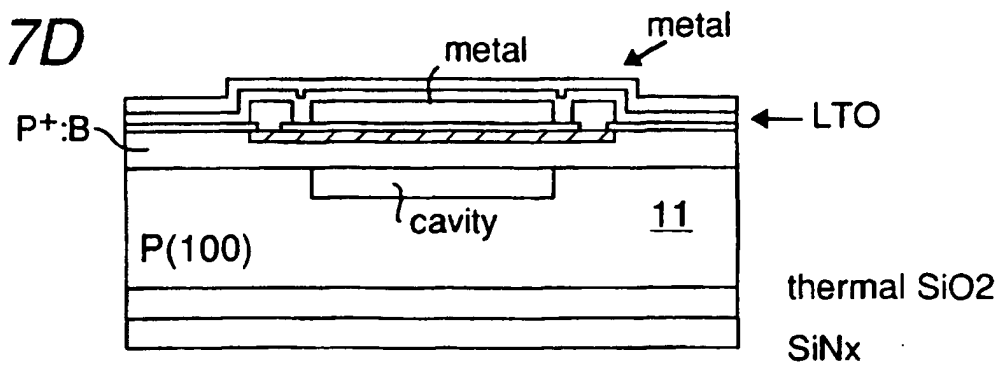


Fig.18A

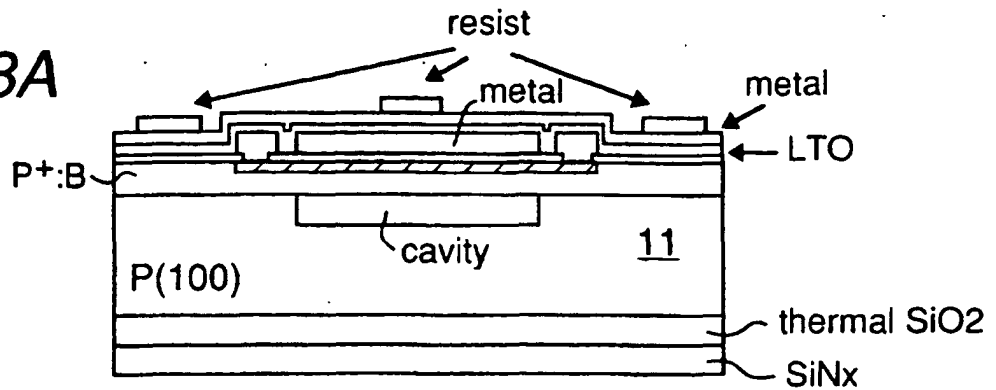


Fig.18B

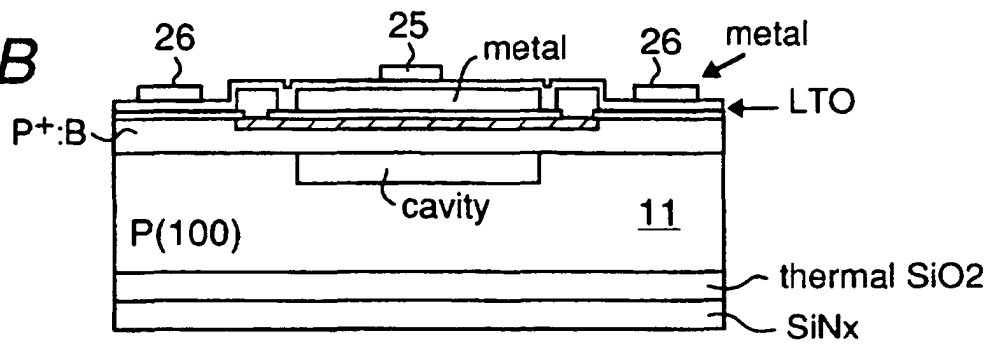


Fig.18C

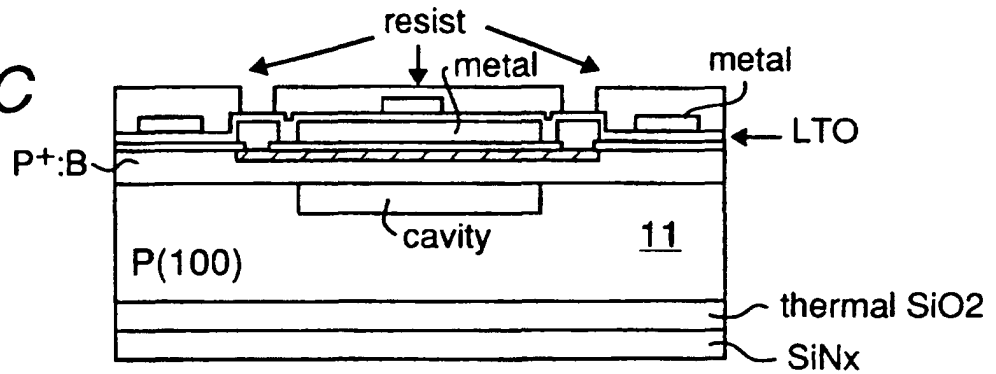


Fig.18D

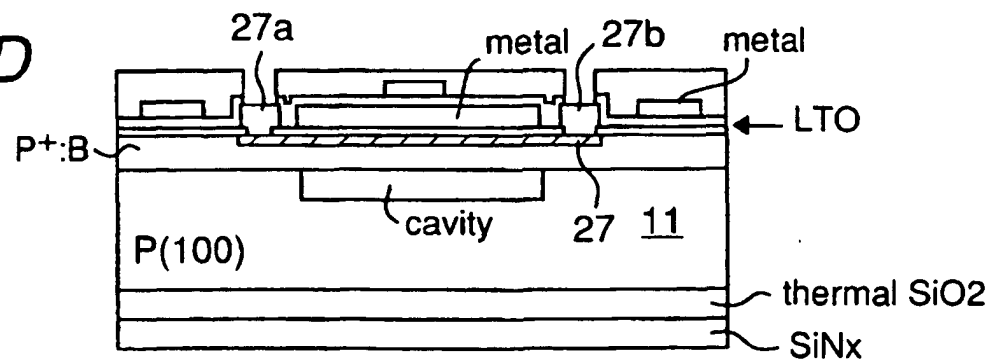


Fig.19

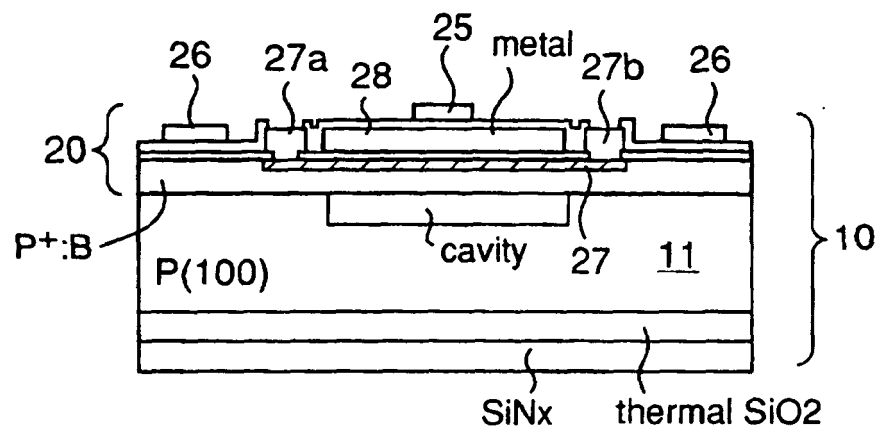


Fig.20A

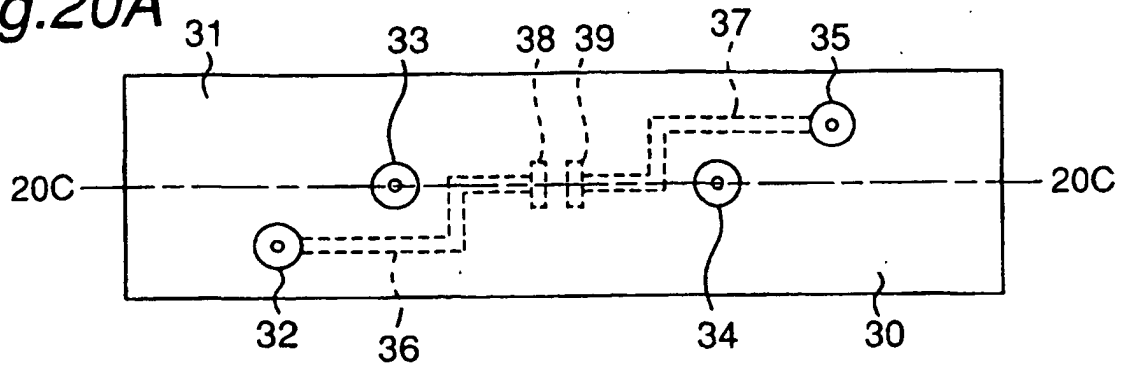


Fig.20B

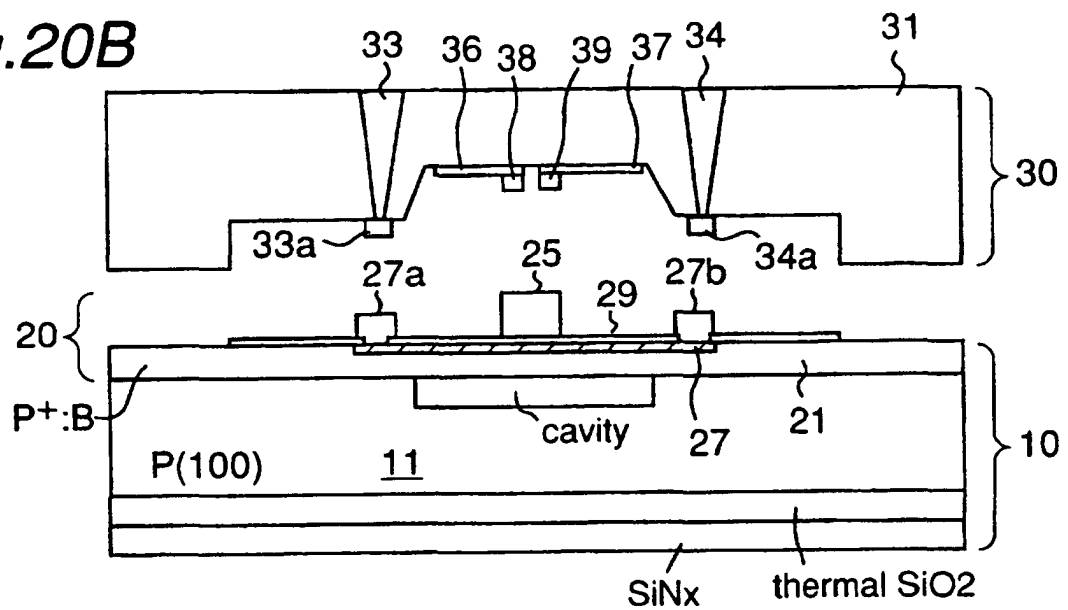
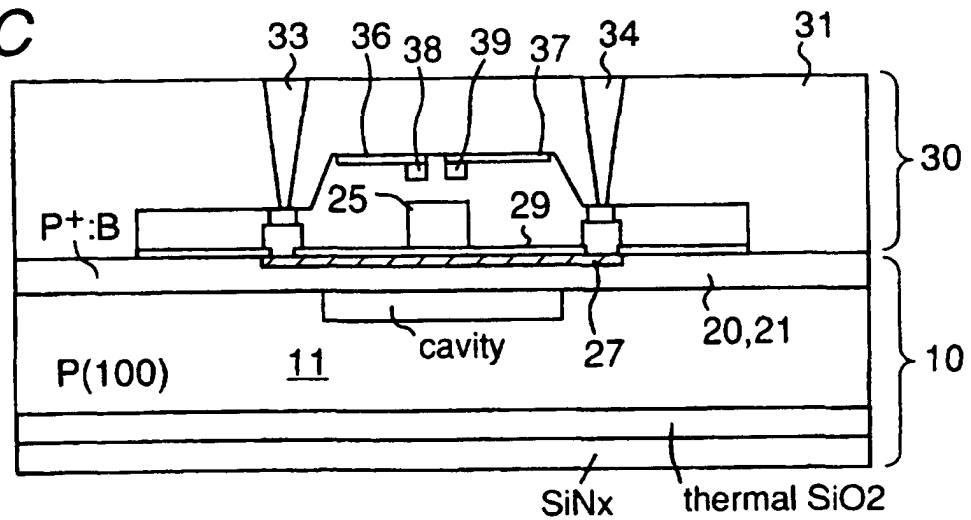
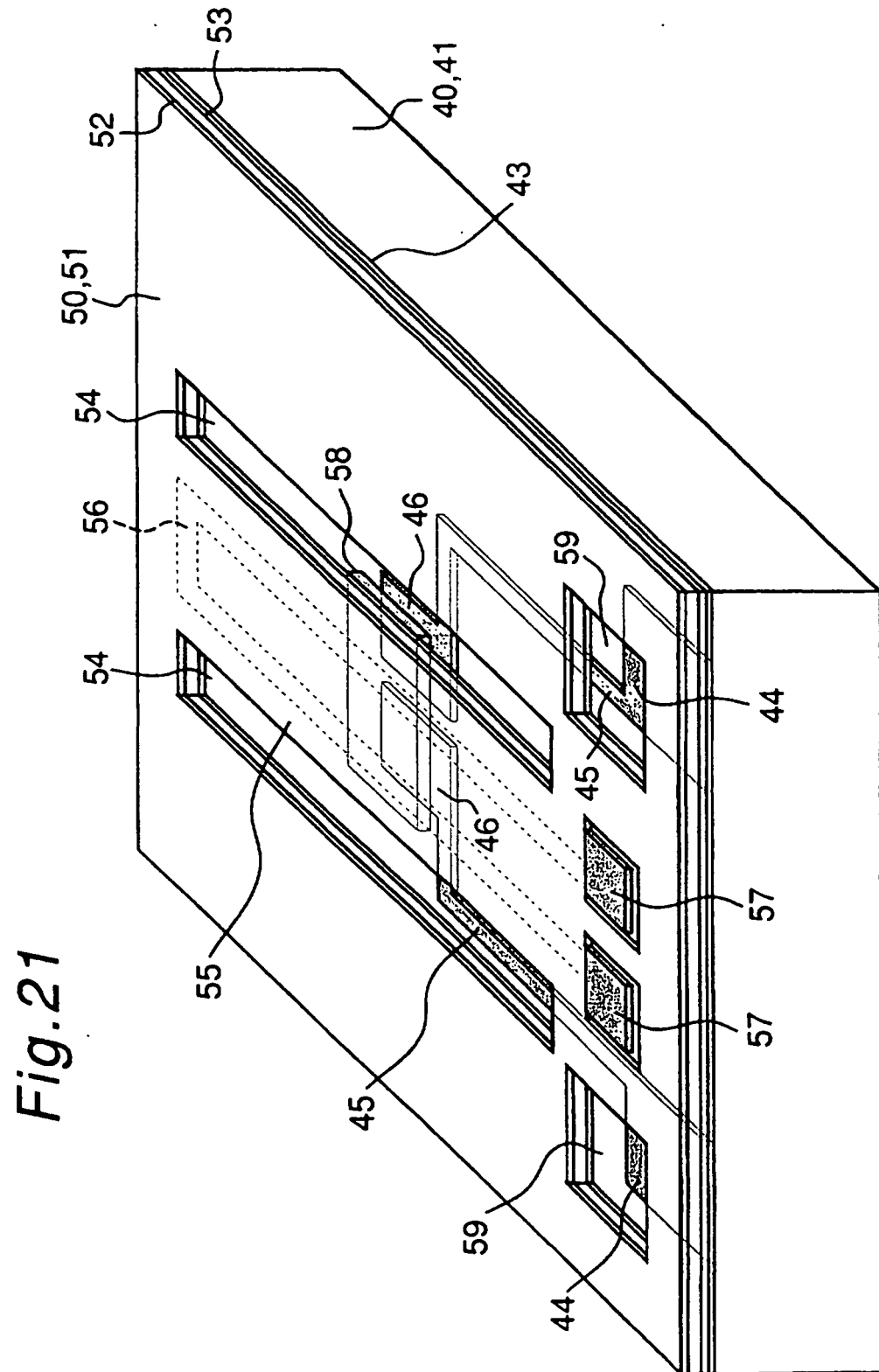


Fig.20C





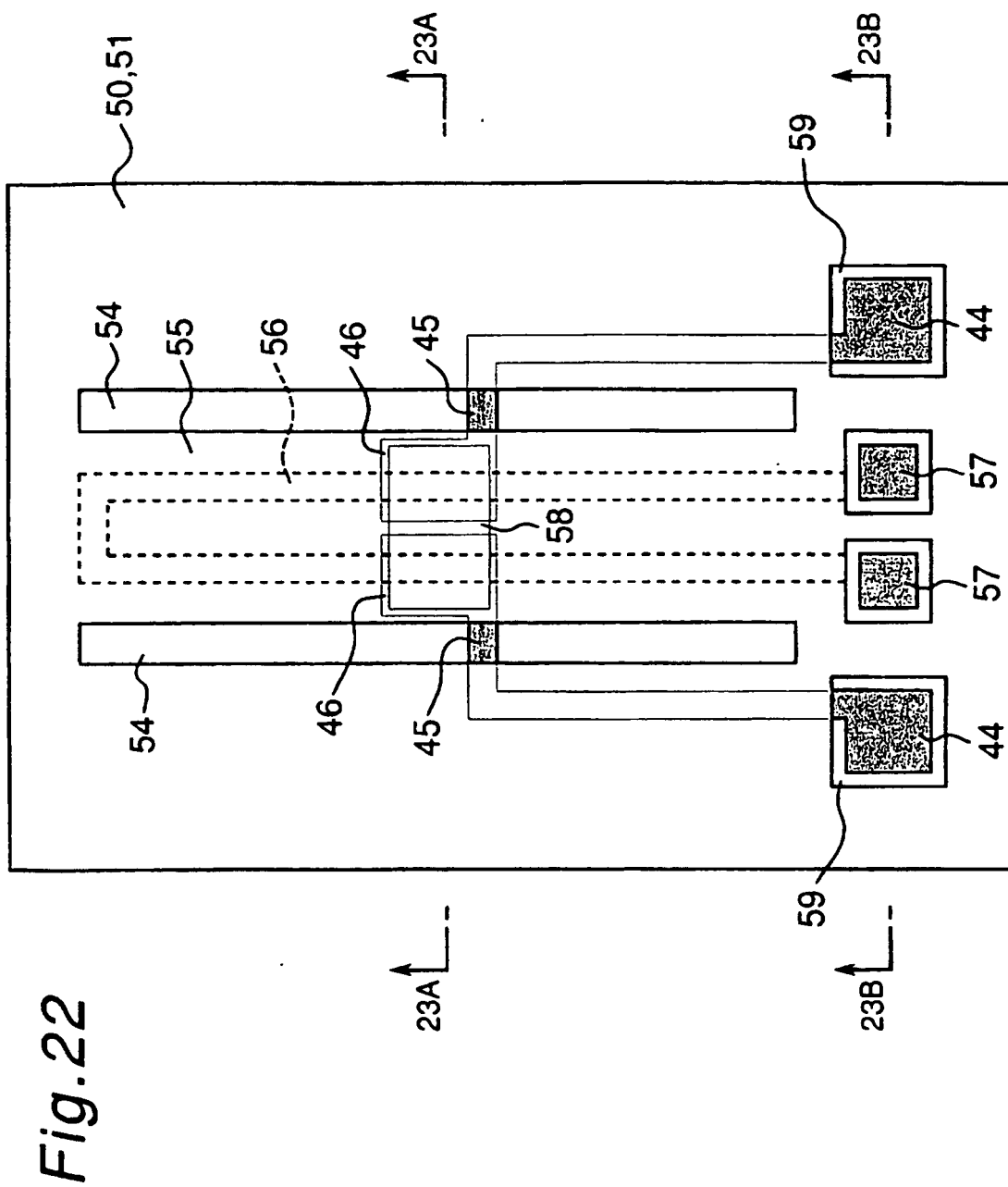


Fig. 23A

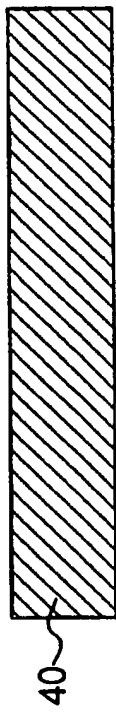


Fig. 23C

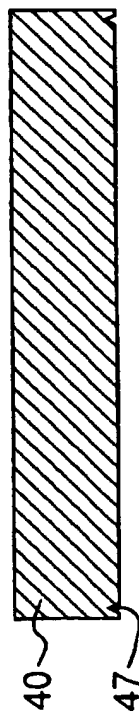


Fig. 23E

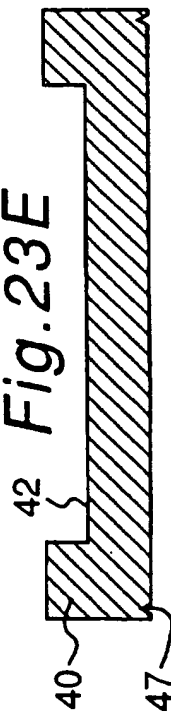


Fig. 23G

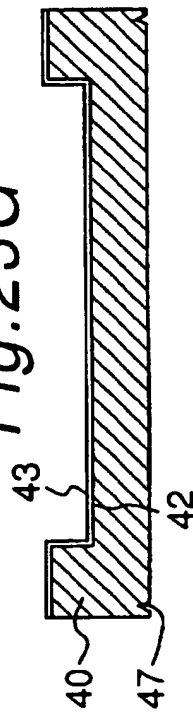


Fig. 23I

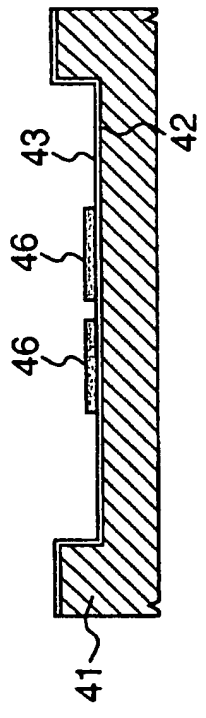


Fig. 23B

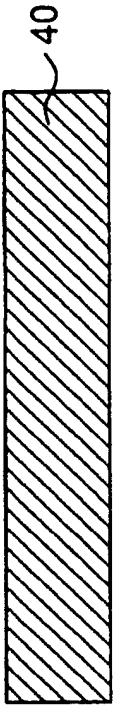


Fig. 23D

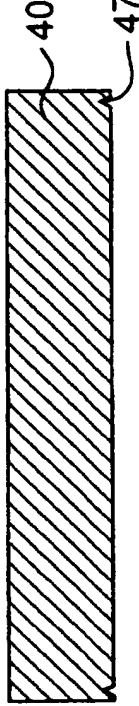


Fig. 23F

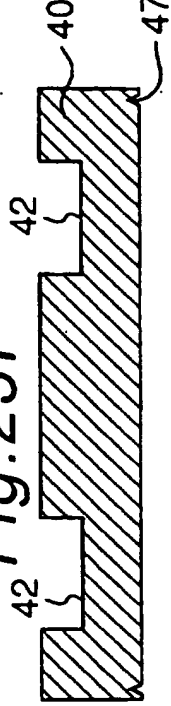


Fig. 23H

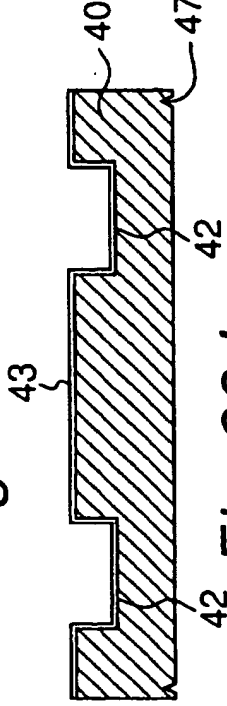


Fig. 23J

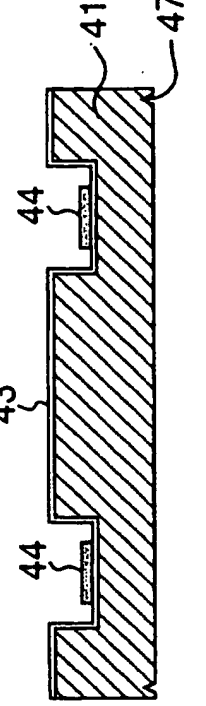


Fig. 24A

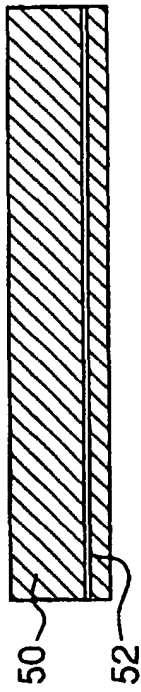


Fig. 24C

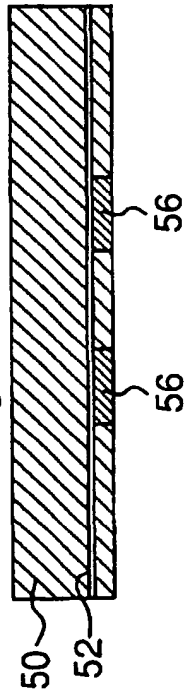


Fig. 24E

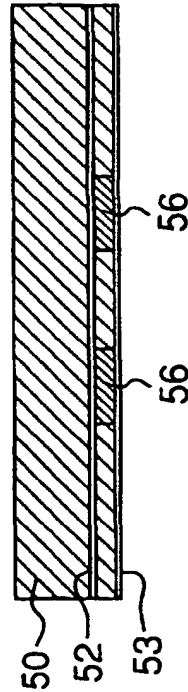


Fig. 24G

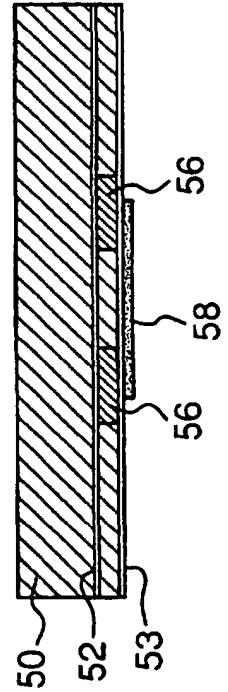


Fig. 24B

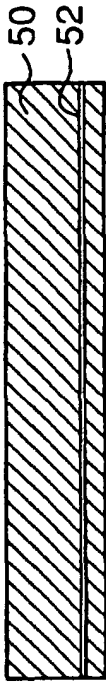


Fig. 24D

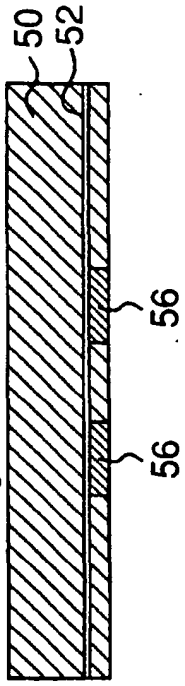


Fig. 24F

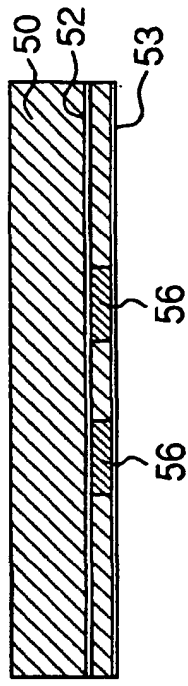


Fig. 24H

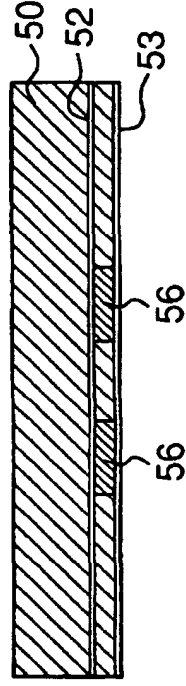


Fig. 25A

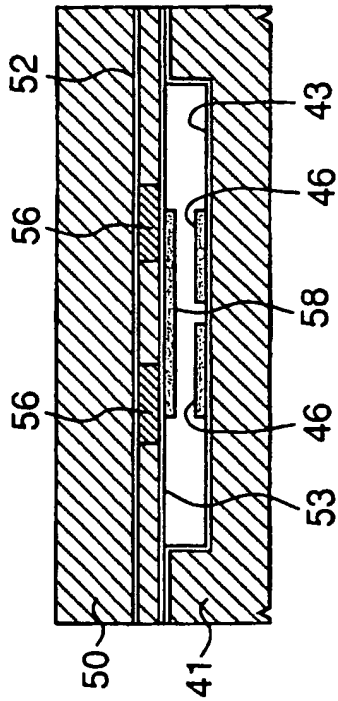


Fig. 25C

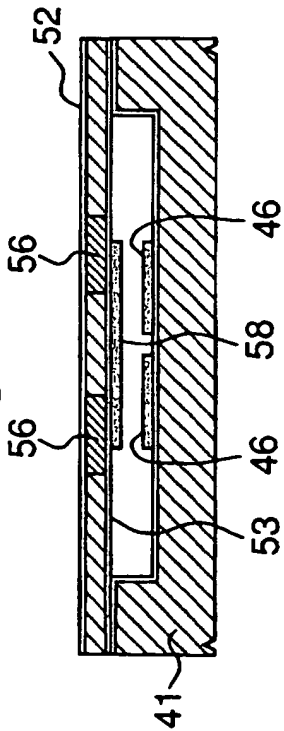


Fig. 25E

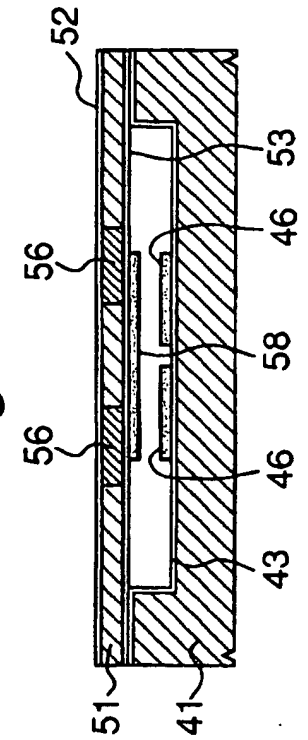


Fig. 25B

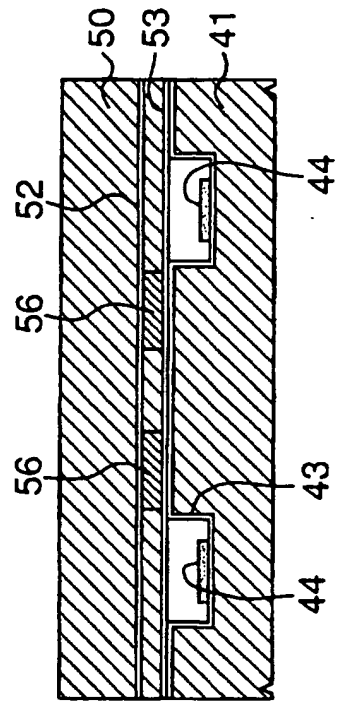


Fig. 25D

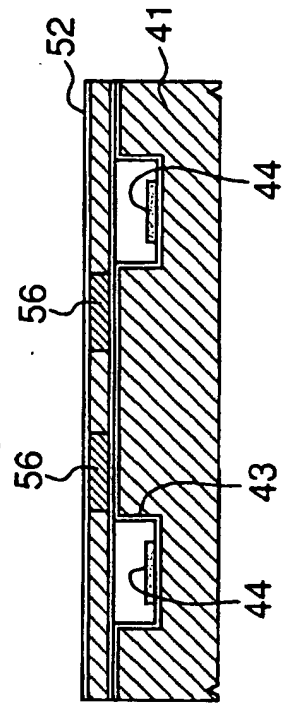


Fig. 25F

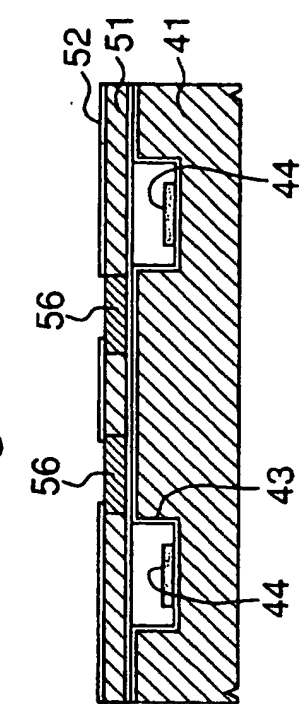


Fig. 26A

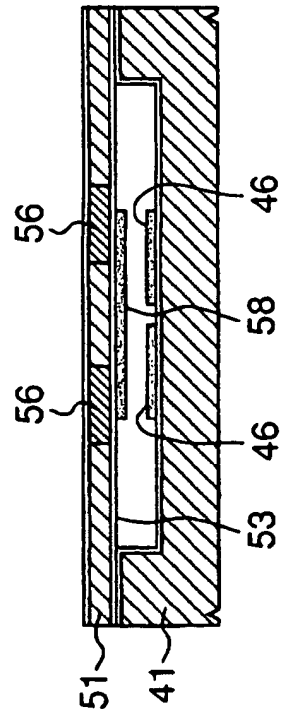


Fig. 26C

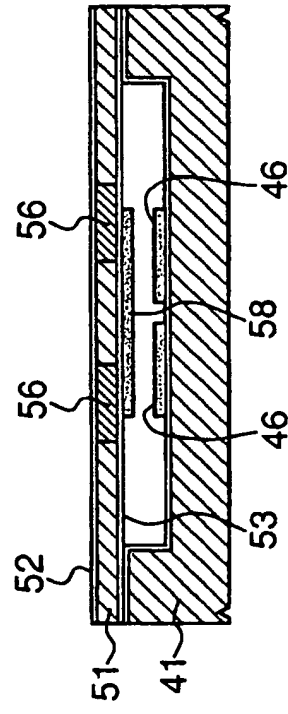


Fig. 26E

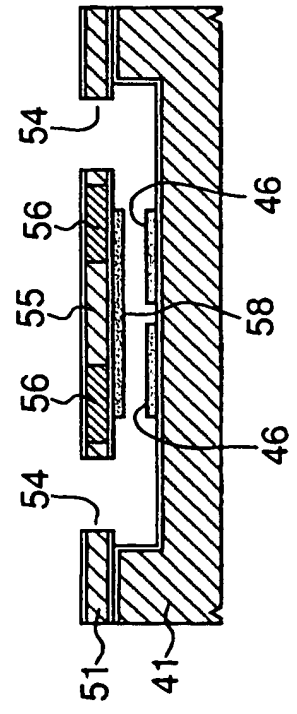


Fig. 26B

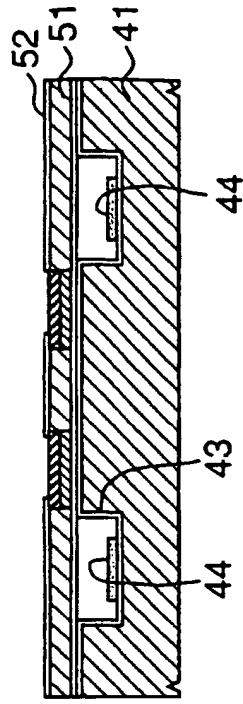


Fig. 26D

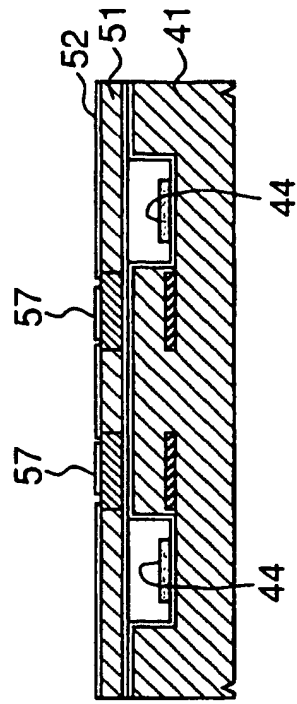
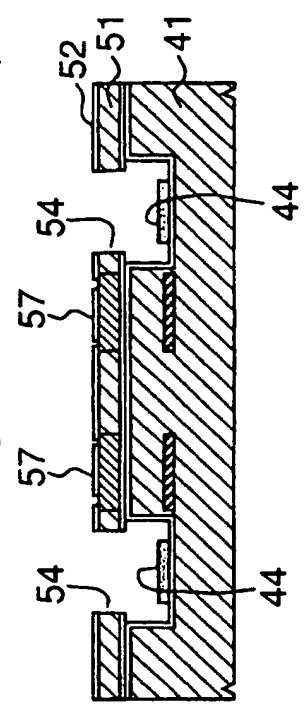


Fig. 26F



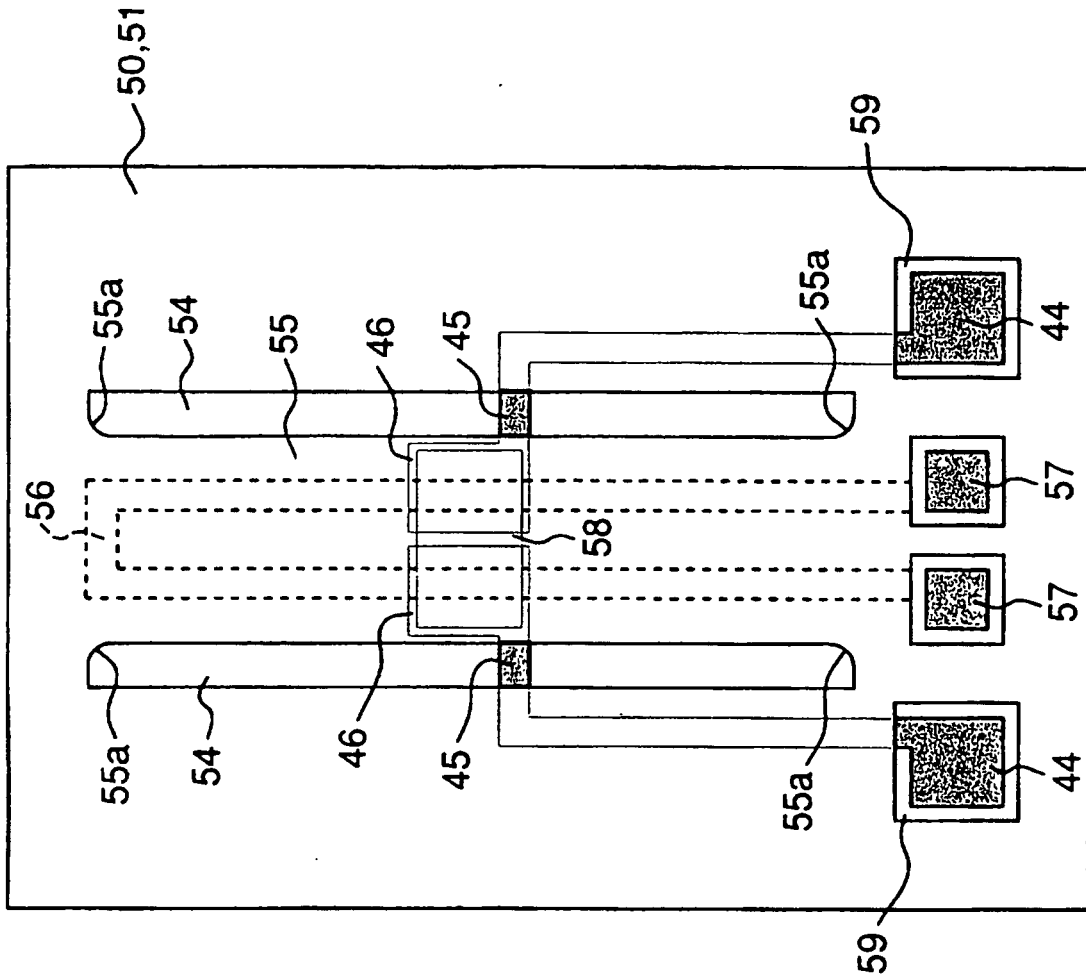


Fig. 27

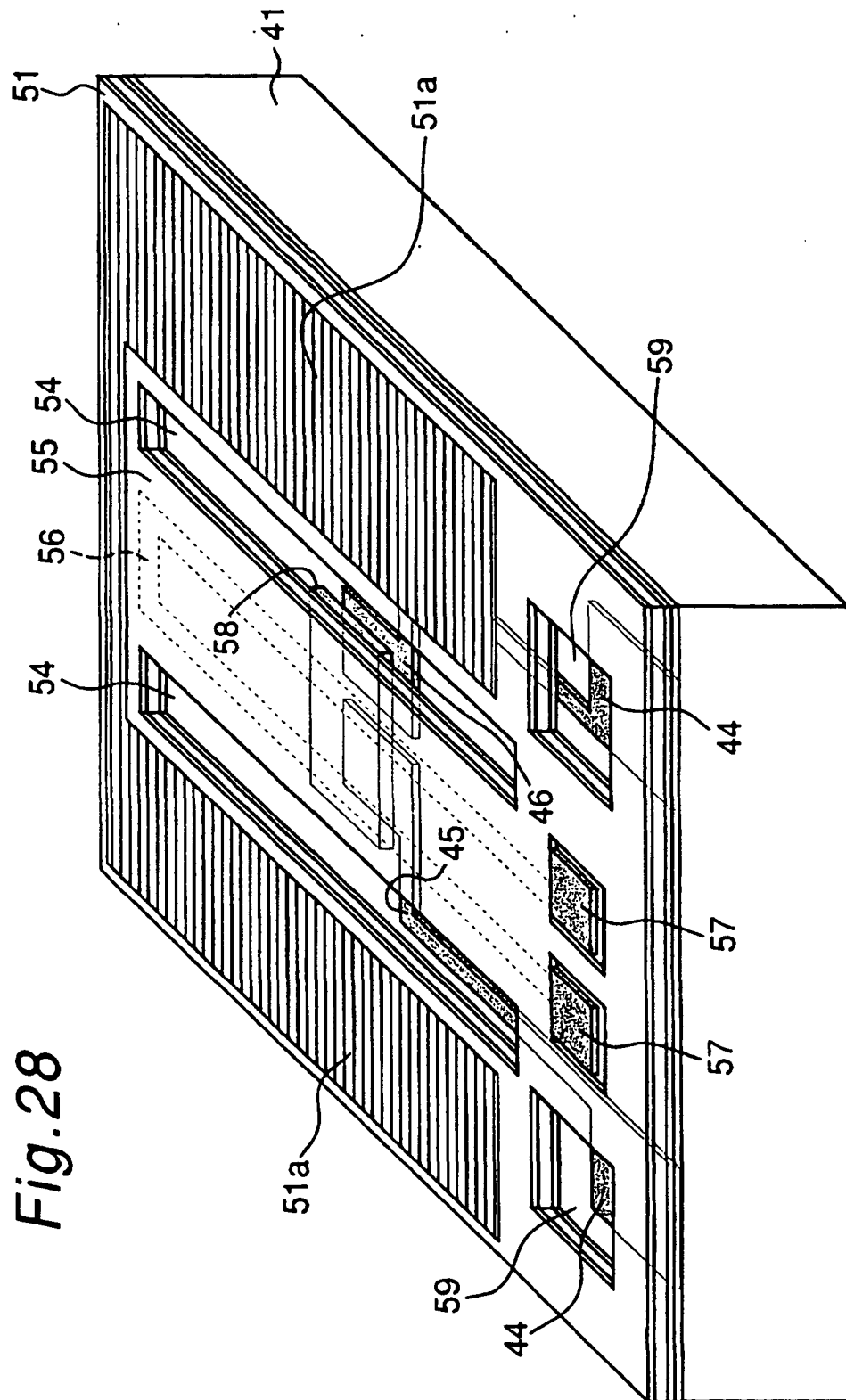
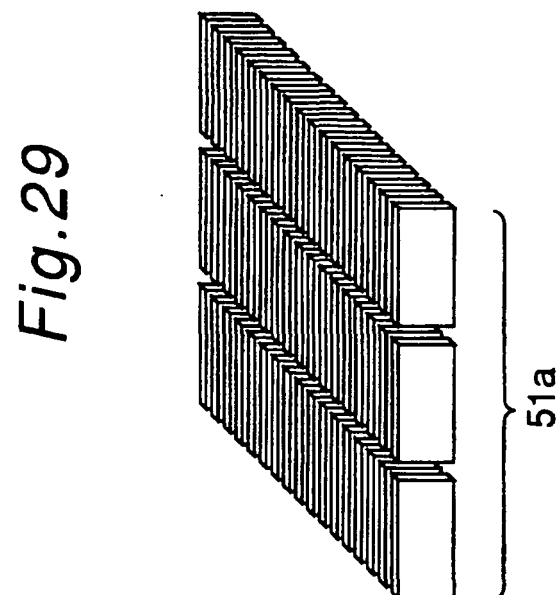


Fig. 28



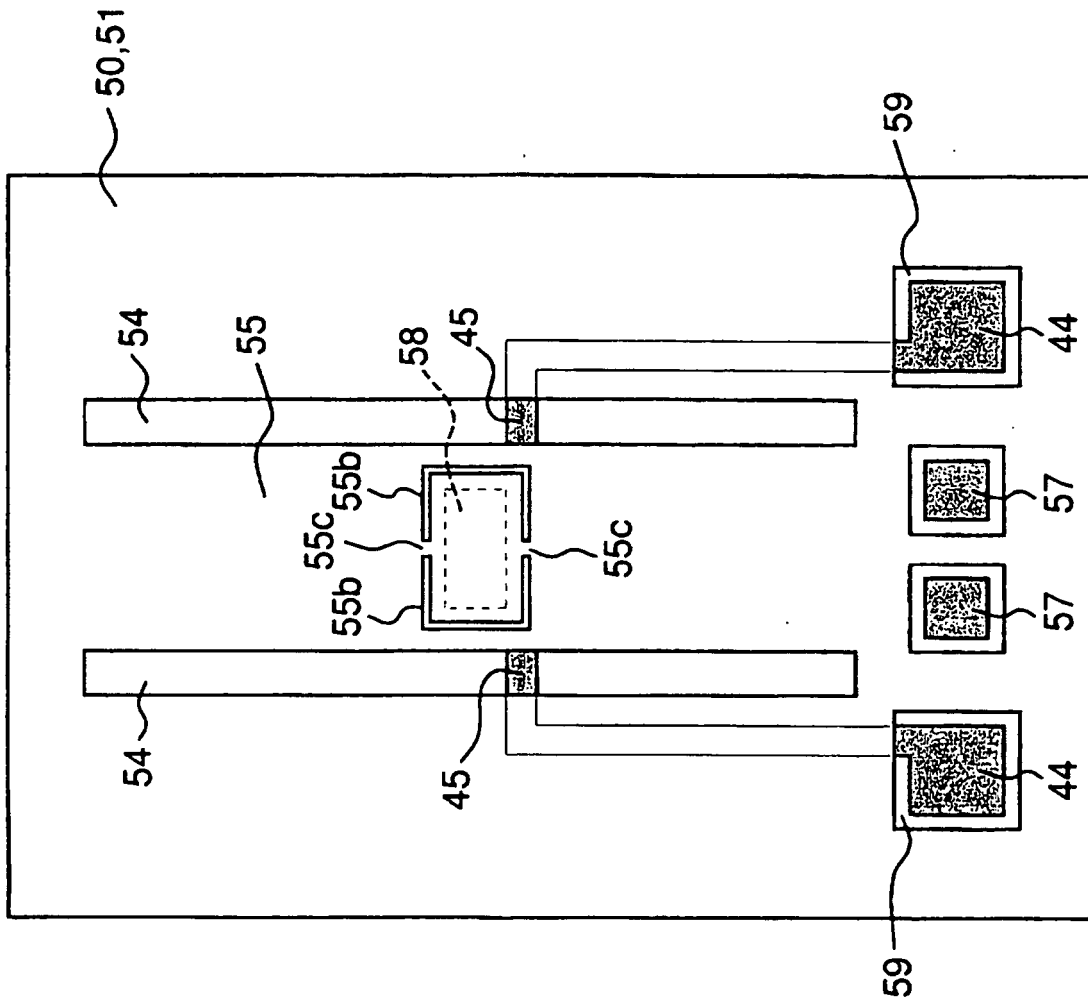


Fig. 30

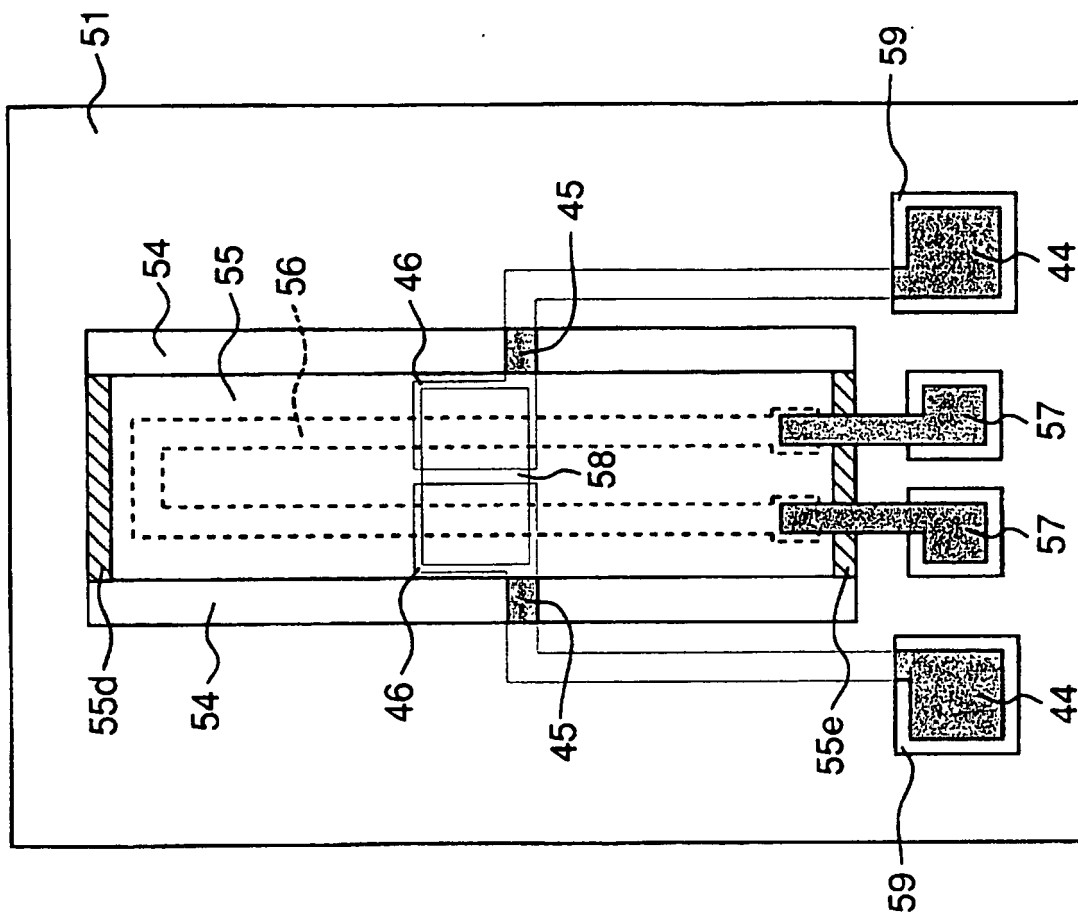


Fig. 31

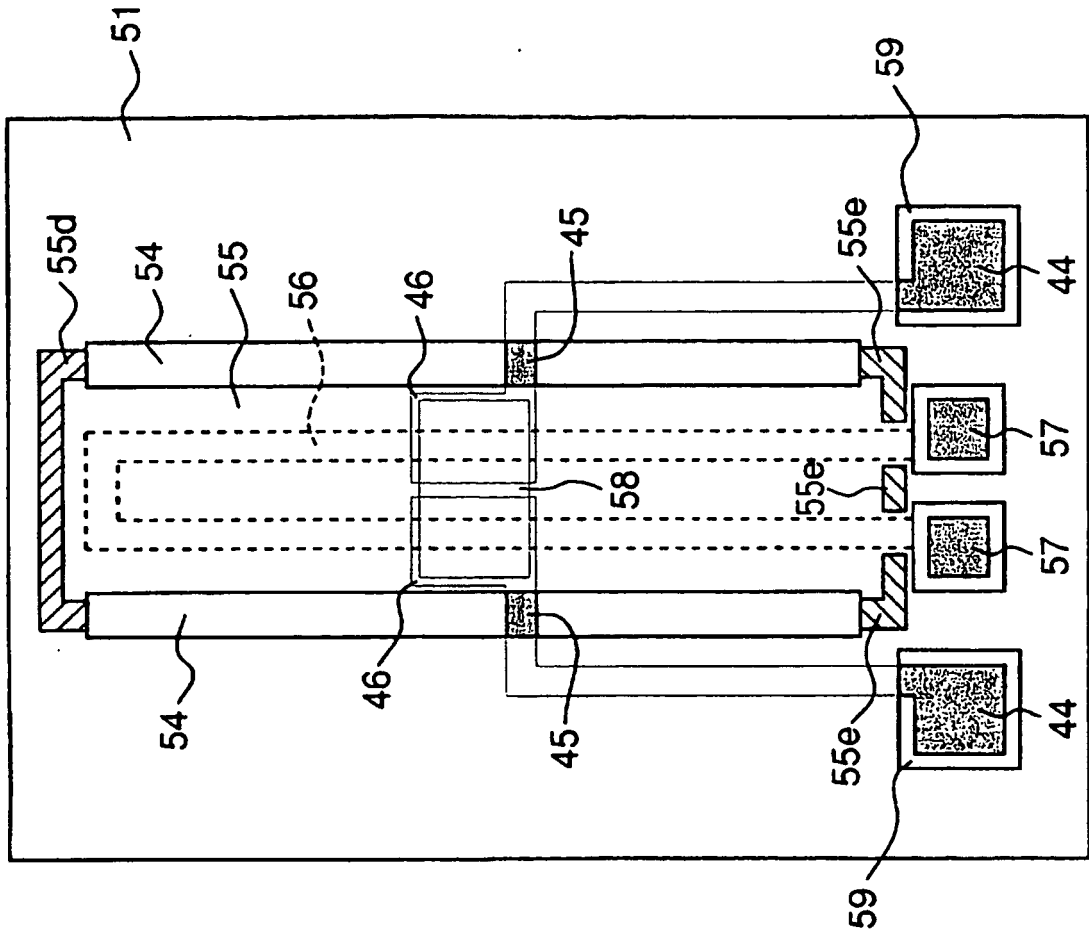


Fig. 32

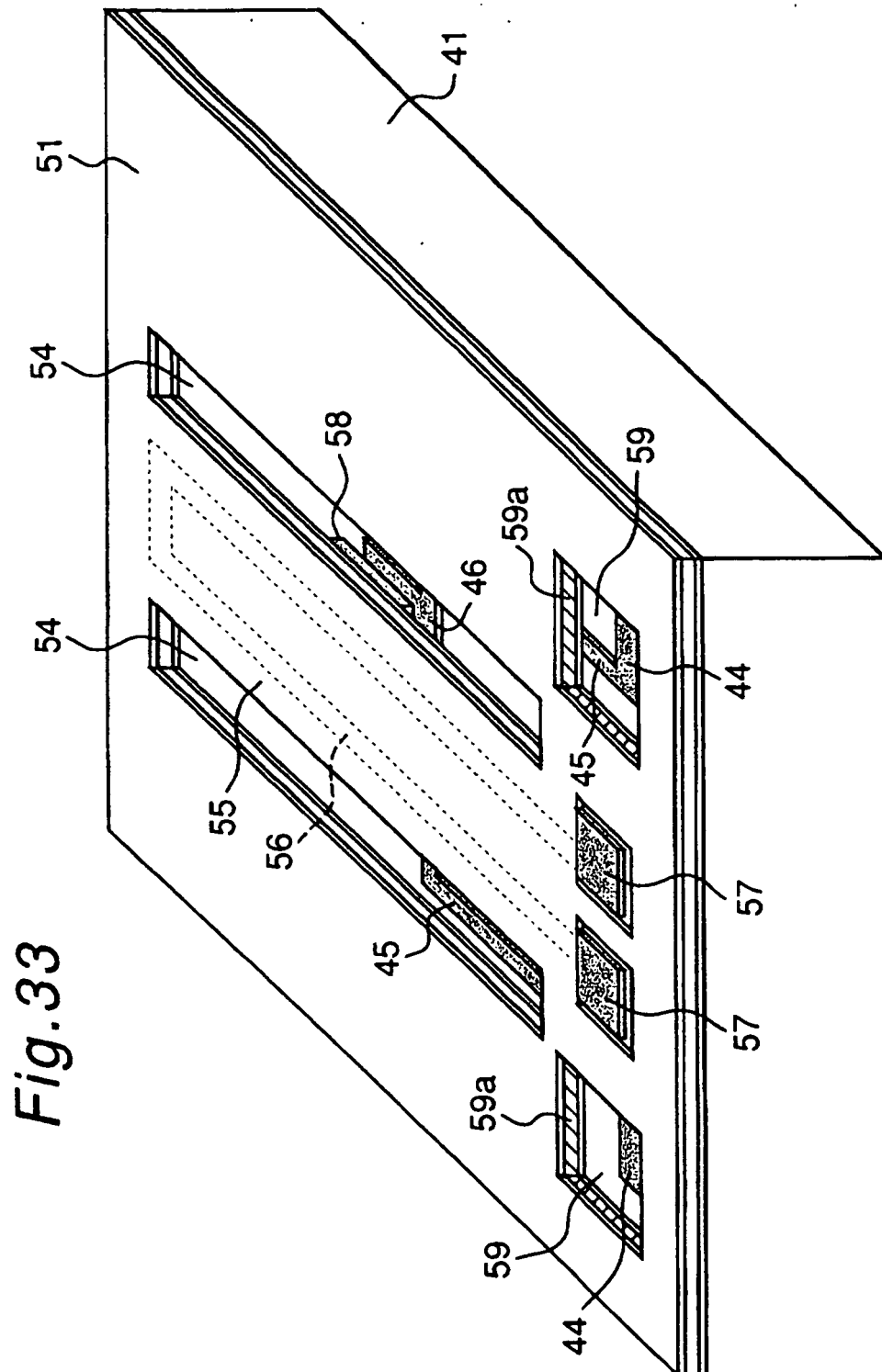


Fig.34

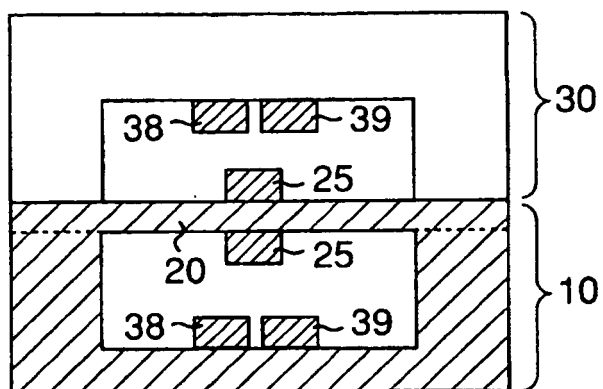


Fig.35

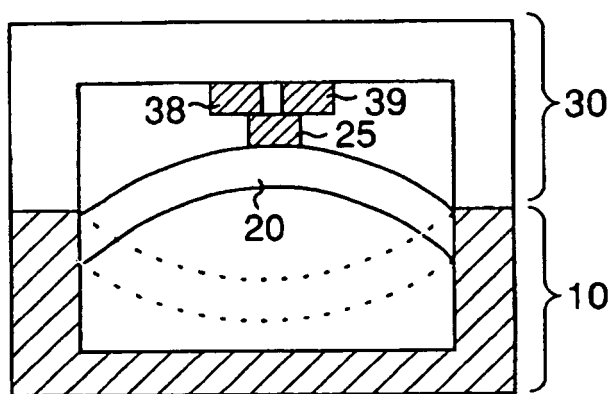


Fig.36

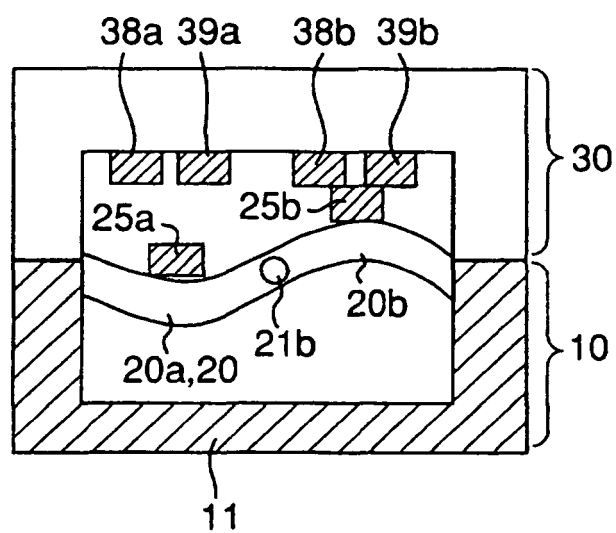


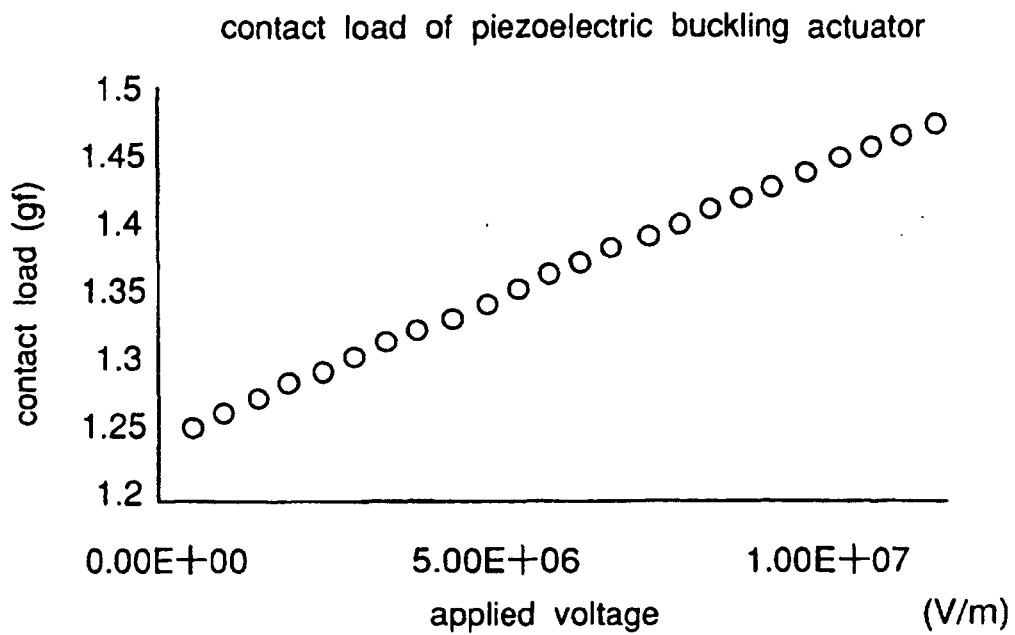
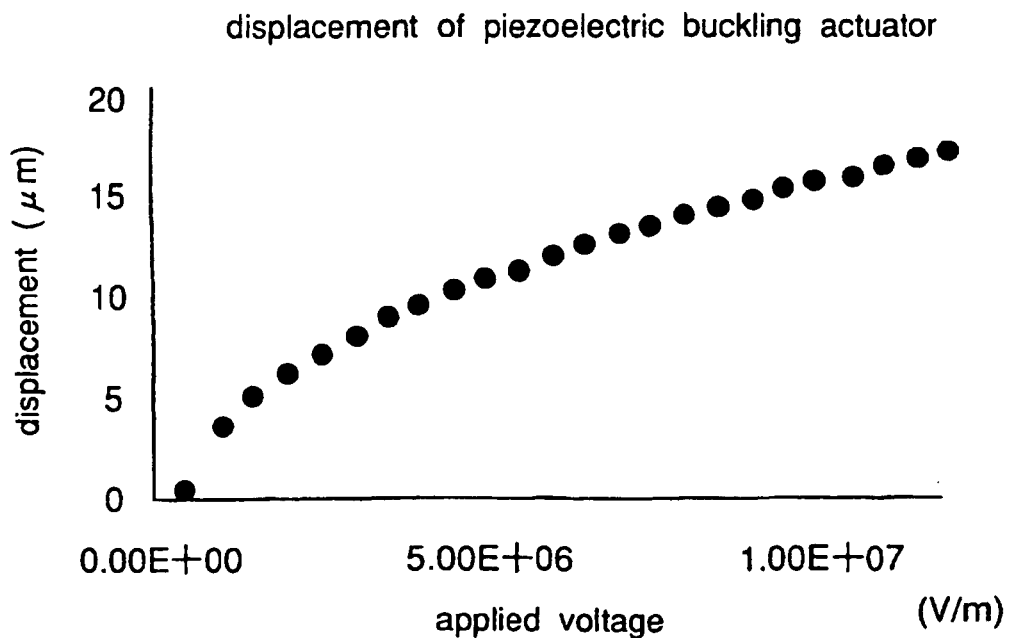
Fig.37A*Fig.37B*

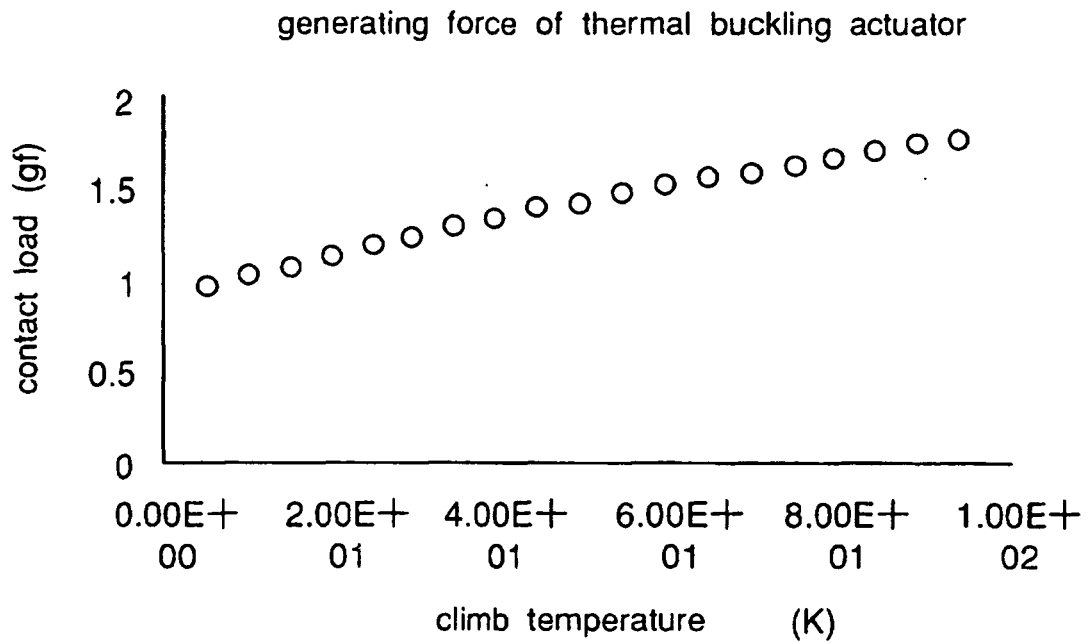
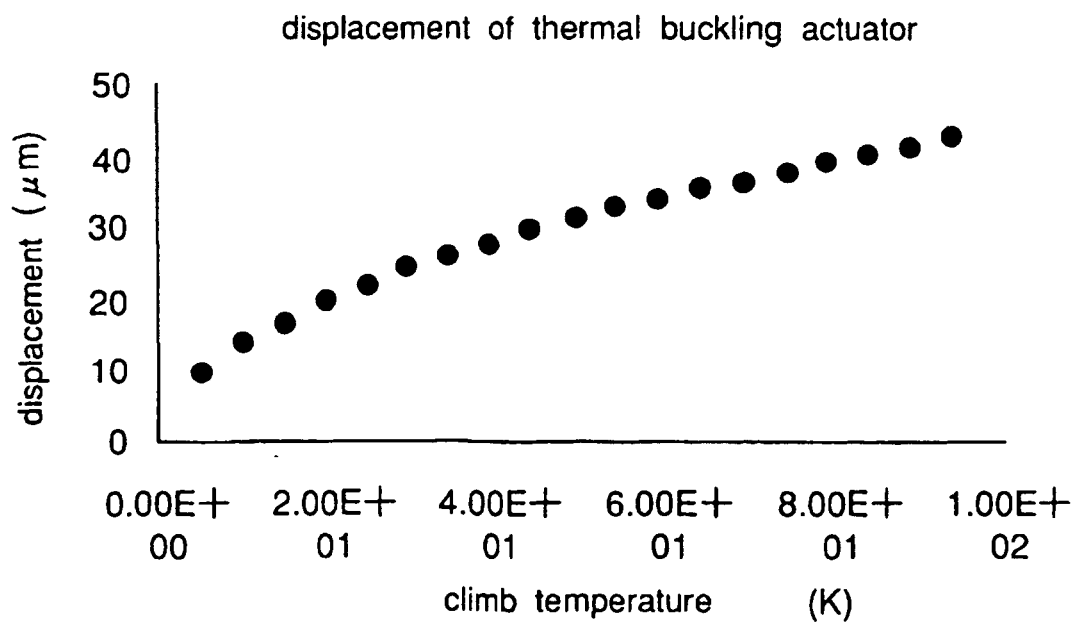
Fig.38A*Fig.38B*

Fig.39A

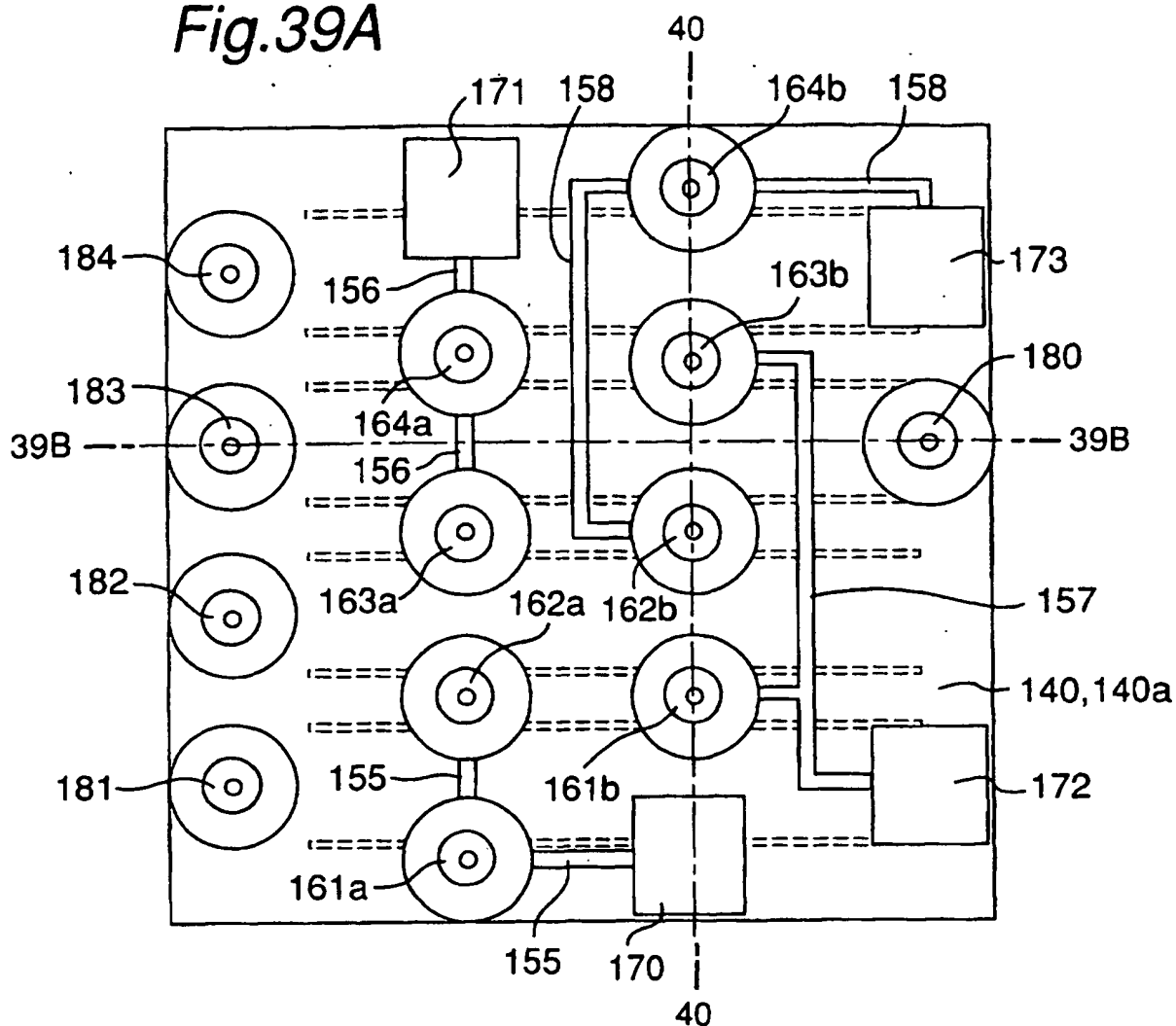


Fig.39B

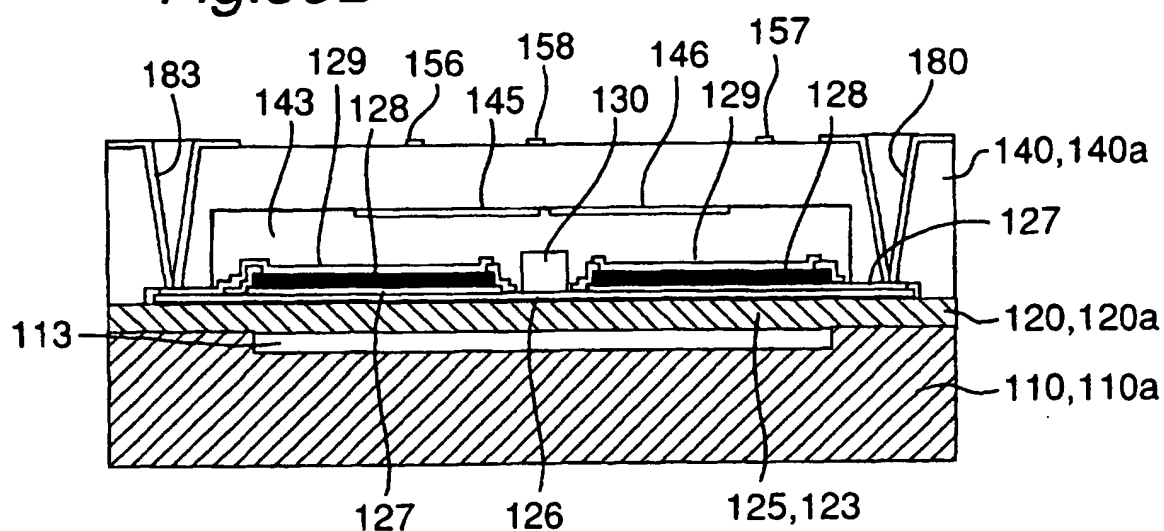


Fig.40

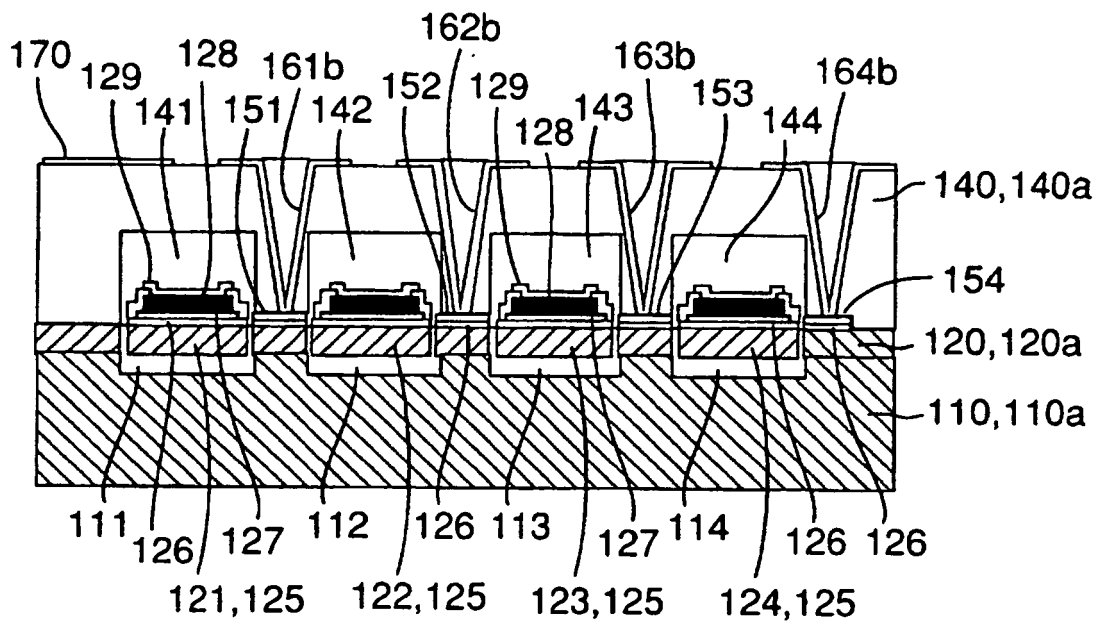


Fig.41A

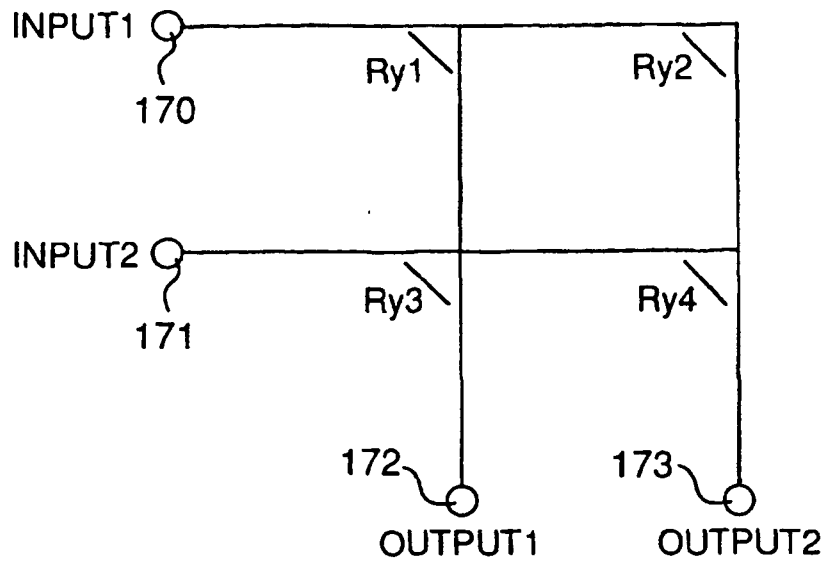


Fig.41B

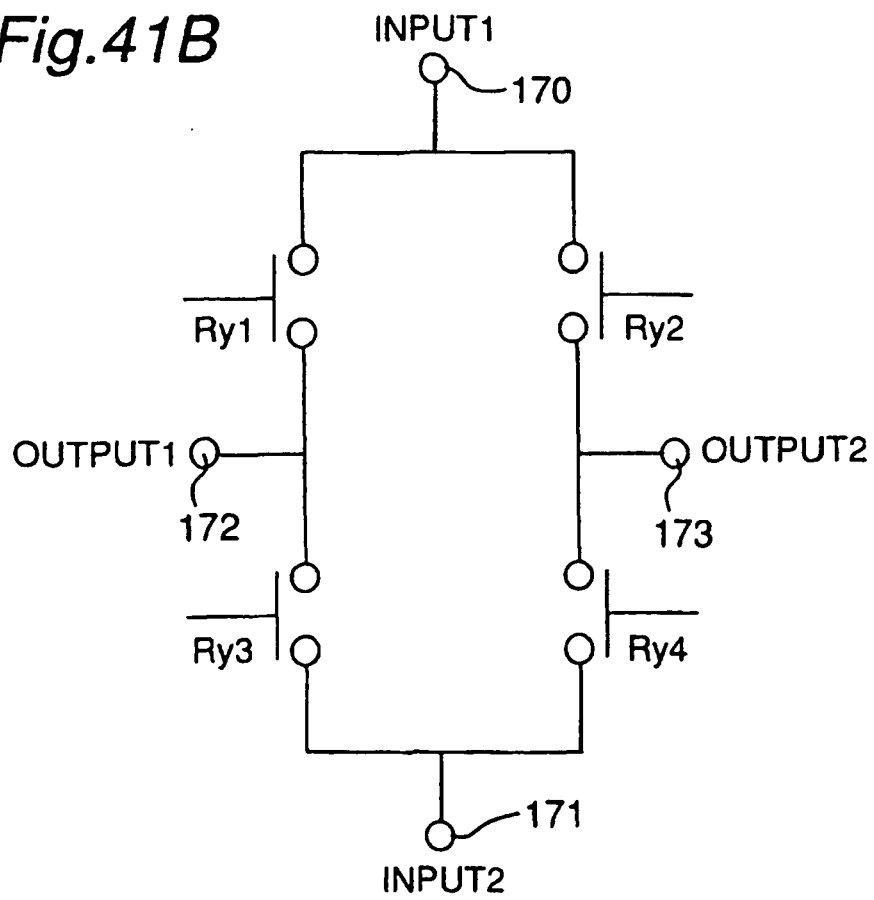


Fig.42A

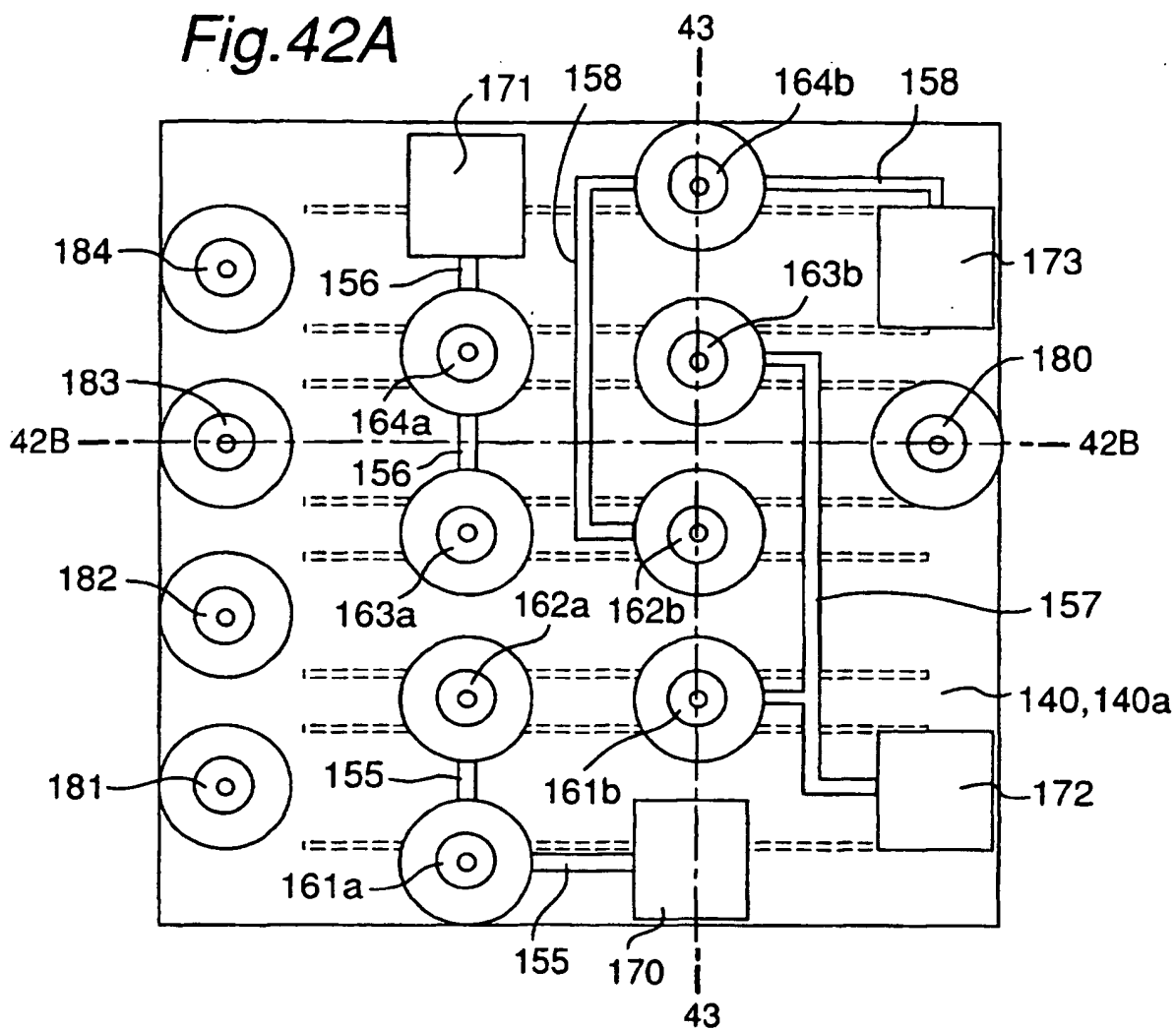


Fig.42B

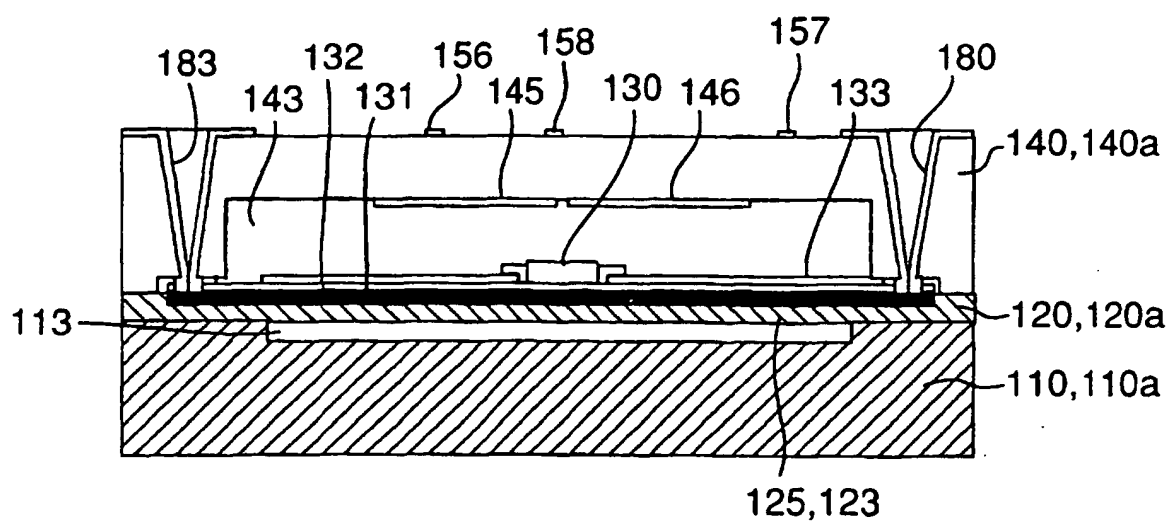


Fig.43

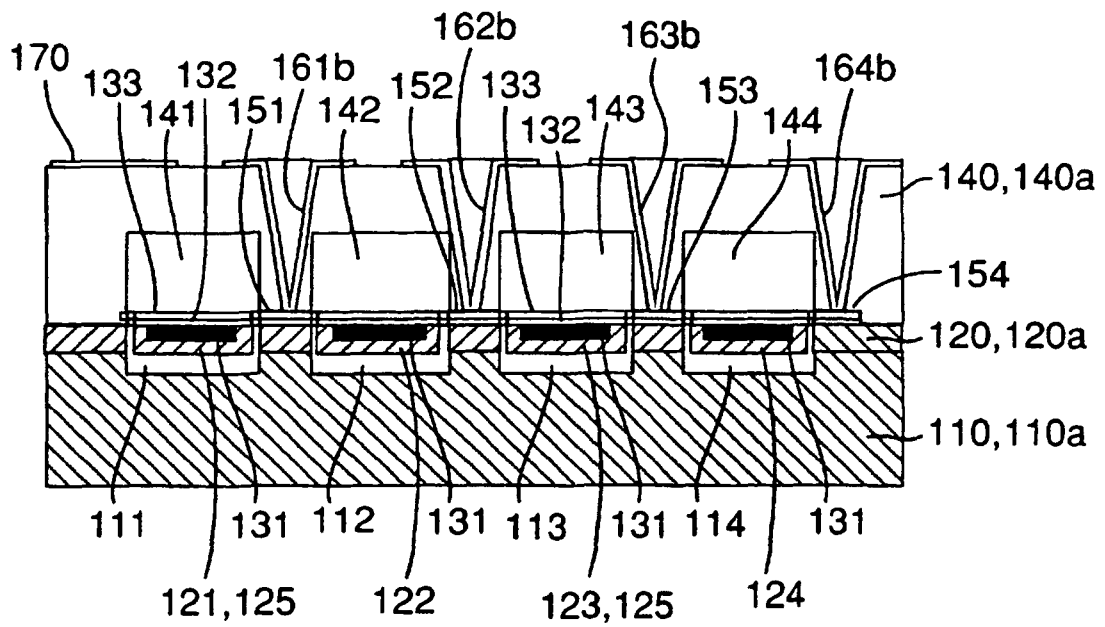


Fig. 44

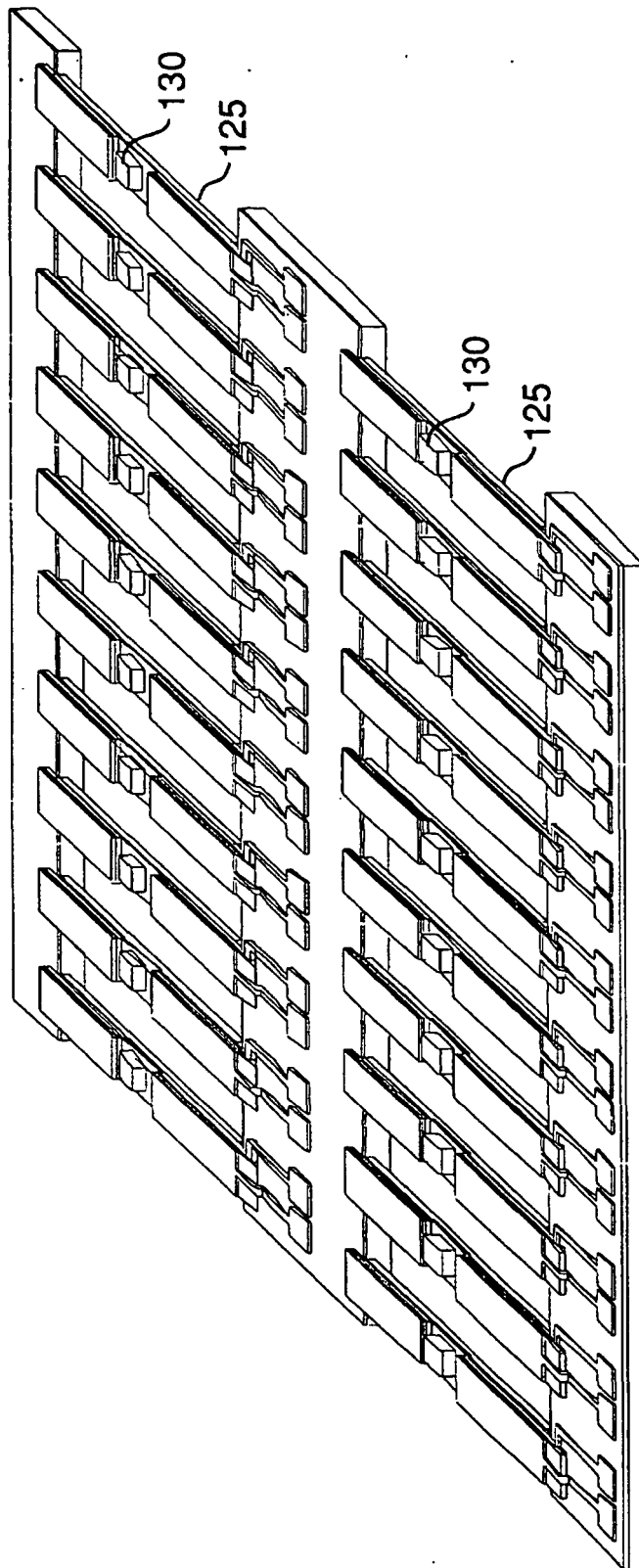


Fig.45